National Park Service
U.S. Department of the Interior

Natural Resource Program Center

Standard Operating Procedures for the Rocky Mountain Climate Protocol

The SOP's in this document reflect updates to the SOP Document:
'NPS_Rocky_Mtn_Climate_Monitoring_Protocol_PreRelease_Draft_Sept9_2009_SOPs.docx' **as referenced in the protocol narrative - Natural Resource Report NPS/IMRO/NRR—2010/222**

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Note: Table and Figure numbering starts over in each distinct SOP.

These unpublished updates posted to NRInfo on March 8, 2011.
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Rocky Mountain Climate Protocol SOP Data Acquisition

Greater Yellowstone & Rocky Mountain Networks: March 2011 version

Change History

Revision History Log

Previous Version #	**Revision date**	**Author**	**Changes made**	**Section and paragraph**	**Reason for change**	**New Version #**
1	11-22-10	Ashton	Added more full description of data acquisition steps from old SOPS of Brent Frakes; Added WASO climate database; Added Canada data Acquire			2010
2010	March 4, 2011	Rob Daley – GRYN, with input from others at GRYN, ROMN, SIEN	General update from lessons learned by multiple users and reviewers, and new collaboration with IMD/NRPC	Various	Scheduled review	March 2011

1 - Introduction

The Rocky Mountain Climate Protocol(RMCP) relies entirely on data acquired from established weather and climate monitoring systems operated by the federal and academic entities listed in Table 1. As of 2010, most tabular climate data (not including geospatial SNODAS and PRISM data sources) are compiled by and managed in an enterprise database operated by the NPS Inventory and Monitoring Division (IMD). This SOP describes the steps required to ensure that parameter values from network weather and Streamgage stations are incorporated into the NPS Enterprise Climate Database. Procedures are included here for downloading COOP, SNOTEL, snow course, and Streamgage data in cases where the IMD cannot acquire, compile, and provide the required data for the network via the NPS IMD Climate Database.

This SOP also describes where and how to download PRISM and SNODAS data, which networks must currently acquire, manage, and analyze on their own.

Table 1. Climate Monitoring Programs/Systems

Agency	Acronym	Data	Web Address
National Oceanic and Atmospheric Administration, National Climatic Data Center	NOAA-NCDC	COOP	http://www.ncdc.noaa.gov/oa/climate/stationlocator.html http://www7.ncdc.noaa.gov/IPS/coop/coop.html
Natural Resource Conservation Service	NRCS	SNOTEL	http://www.wcc.nrcs.usda.gov/snow/
Natural Resource Conservation Service	NRCS	Snow Course	http://www.wcc.nrcs.usda.gov/snow/snowhist.html
U.S. Geologic Survey	USGS	Streamgage	http://waterdata.usgs.gov/nwis
NOAA Climate Diagnostics Center, Physical Science Division	NOAA-CDC	Climate and Oceanic indices	http://www.cdc.noaa.gov/data/climateindices/list/
National Snow and Ice Data Center, University of Colorado, Boulder, CO	NSIDC	SNODAS	http://nsidc.org/data/g02158.html ftp://sidads.colorado.edu/DATASETS/NOAA/G02158/
PRISM Climate Group	PRISM	PRISM	http://prism.oregonstate.edu/
Drought Indices and maps			http://drought.unl.edu/dm/monitor.html

2 - Acquiring Common Data by Request to the NPS Inventory and Monitoring Division

Station data from COOP, SNOTEL, Snow Course, and USGS Streamgage systems are acquired and managed by the NPS IMD based on a request from each network using the instructions found in standard operating procedure, "*Requesting Essential Parameter Values from COOP, SNOTEL, Streamgage, and Snow Course Data for Acquisition, Compilation, Basic Quality Control, and Distribution by the NPS Natural Resource Program Center*" (Frakes 2010, NRInfo RefCode = 2166927). Networks normally submit the initial request for station data to the NPS IMD before April 1st. IMD automatically acquires new data each year for submitted stations once final data is available from the providers. Note that final station data from some providers is not available for up to five months following the collection date required. For example, final COOP data from December of 2010 may not be available from NOAA until April, 2011. Networks can add and remove stations using instructions found in the SOP for requesting stations. Maintain a station list for each reporting period in a trusted and stable location such as on a SharePoint site and/or within the project's folder structure on a backed-up network server. This station list is required content in status and trend reports.

Steps for requesting station data:

(1) Make a list of all COOP, SNOTEL, SnowCourse, and USGS Streamgage sites that are relevant to the park or network. This list can be derived primarily from climate inventory reports for NPS Inventory and Monitoring networks (http://www.wrcc.dri.edu/nps/reports.php) or search NRInfo for 'climate inventory'. A common criterion is to include all stations within 40 km of a park's boundary.

(2) Follow the instruction in the latest version of the standard operating procedure, "*Requesting Essential Parameter Values from COOP, SNOTEL, Streamgage, and Snow Course Data for Acquisition, Compilation, Basic Quality Control, and Distribution by the NPS Natural Resource Program Center*" (Frakes 2010a, NRInfo RefCode = 2166927).

(3) For all subsequent years, review the list from the previous year and if necessary follow the instructions in step 2 above to submit additional stations. If no changes are required for a reporting period, then confirm this in an email to the IMD Climate Database Administrator, as a courtesy.

3 - Acquiring and Uploading Improved and Other Data to the NPS IMD Climate Database

The NPS Enterprise Climate Database accommodates data from providers other than COOP, SNOTEL, Snow Course, and Streamgage, as well as data from these providers that is locally acquired, checked, and improved (e.g. by adding missing values to a data set based on a review of the original field data collection form B-91). Local users are responsible for acquiring and correctly formatting these data sources in order to submit them for upload. This is useful to compile and upload data from stations in Canada, remote automated weather stations (RAWS), or other relevant sources. RAWS data may be uploaded by IMD in the future, but in the current release Networks must acquire these data on their own. The same procedures apply to data from COOP, SNOTEL, Snow Course, and Streamgage providers that have received local quality control and improvements. To submit improved and other data sources to the NPS Enterprise Climate Database, follow the instructions in the most recent version of standard operating procedure, "*Submitting Data for Upload to the I&M Enterprise Climate Database*" (Frakes 2010b, NRInfo RefCode = 2166928). This is normally completed and submitted by April 1st of each year.

Steps to download data from Environment Canada (for GLAC):

(1) Go to Canada Water Survey at: http://www.wsc.ec.gc.ca/hydat/H2O/index_e.cfm (Figure 1). Enter station number for Waterton River: **05AD003**. Hit Next.

(2) From drop down menus, choose report data type as "daily data" and report output type as "date_data format csv". Click on "Obtain Report".

(3) On the next screen, click on "Click here to download the file"

(4) The data will appear on a new page. Use the menu or right click to "save page as". Choose a name and location for your file.

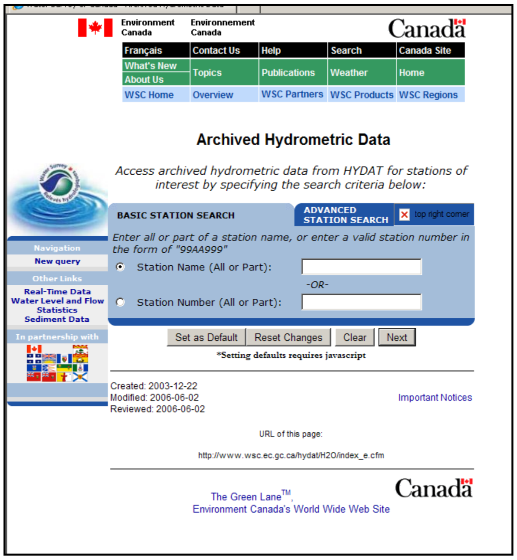

Figure 1. Water Survey Canada

(5) Open saved file in spreadsheet and cut and paste gage data into the data submission form.

(6) Follow steps above to submit data to WASO. The following metadata should be included:

Agency Name and Contact: Environment Canada
National Inquiry Response Team
77 Westmorland Street; Suite 260
Fredericton, New Brunswick E3B 6Z3
Fax: 506-451-6010 phone: 819-994-0736
http://www.wateroffice.ec.gc.ca/mainmenu/contact_us_e.html

Length of Record: 19080601 to present

(7) For Canada Climate Data: Navigate to daily data for Waterton Park Gate ID 3056214 (Figure 2).
http://www.climate.weatheroffice.gc.ca/climateData/dailydata_e.html?Prov=XX&timeframe=2&StationID=26850&Day=1&Month=7&Year=2010&cmdB1=Go

(8) Choose year and scroll to bottom of the page. Choose download data as CSV by clicking on CSV. Save file.

(9) Repeat this for all years of interest.

(10) Follow steps above to submit data to WASO. The following metadata should be included:

Agency Name and Contact: same as above

Length of Record: 19940917 to present

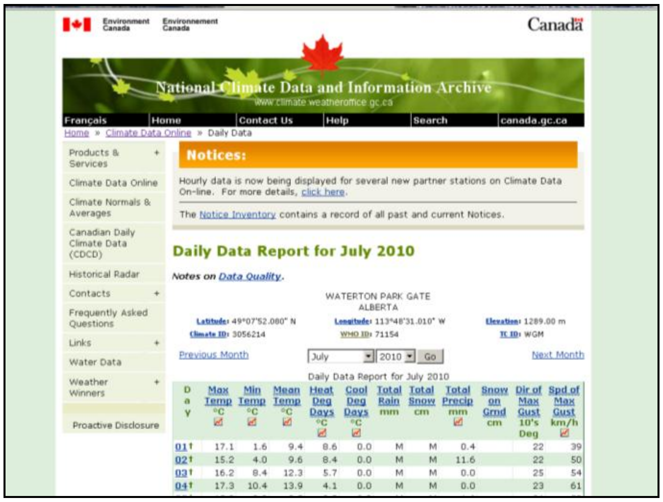

Figure 2. Canada Climate Data for Waterton Gate

4 - Acquiring PRISM data

Given the relatively sparse network of climate stations and complex topography in the Rocky Mountains, grid-based estimates of precipitation and temperature provide a useful overview of climatic conditions in the area. These estimates rely on a statistical modeling technique that interpolates precipitation values from weather stations while also accounting for the effects of aspect and elevation. Known as the Parameter-elevation Regression on Independent Slopes Model (PRISM; http://www.prism.oregonstate.edu/), this approach has a long history of use in the western United States, and it has been shown to provide highly robust products in a wide variety of studies (Daly et al. 2008).

Steps for downloading PRISM data:

Note to users: Other instructions and procedures are available from other NPS and outside sources to acquire and process PRISM data. Users should follow the instructions that work best for their situation. The following steps are one way to accomplish this task.

(1) Navigate to the PRISM website: http://prism.oregonstate.edu/

(2) Once at the site, navigate to the monthly data (Figure 3) and select gridded data for the analysis products (Figure 4).

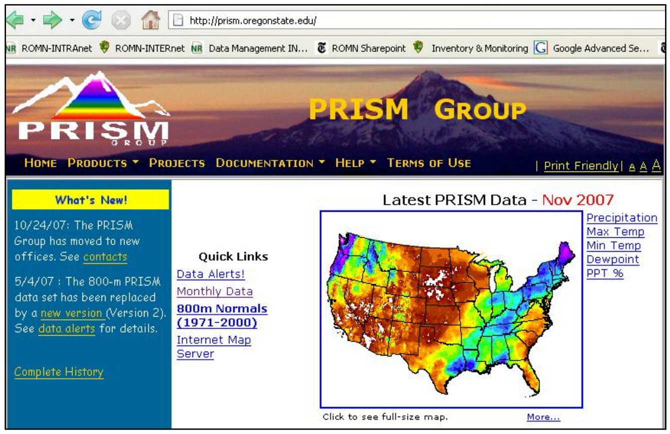

Figure 3. Selecting Monthly Data from the PRISM Home Page

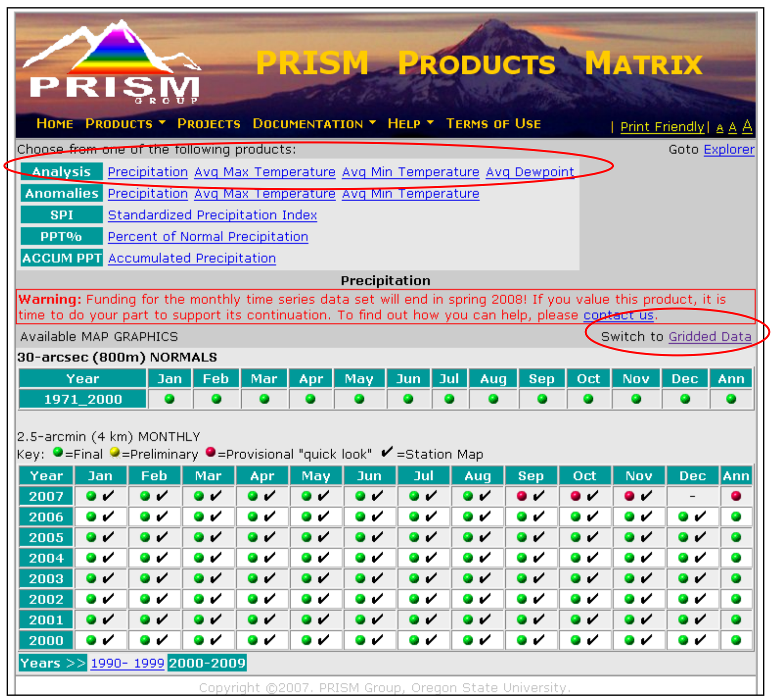

Figure 4. Selecting Gridded Data for the Analysis Products

(3) The following data should be collected from PRISM:

- Precipitation;
- Average Maximum Temperature;
- Average Minimum Temperature;

All months must be green. Green indicates the data is in final form. For instance, Figure 4 indicates that September-November are still provisional and should **not** be downloaded and processed.

Selecting (clicking on) a month links to a screen similar to Figure 3. This screen shows a map of that month and provides an option for downloading the gridded data.

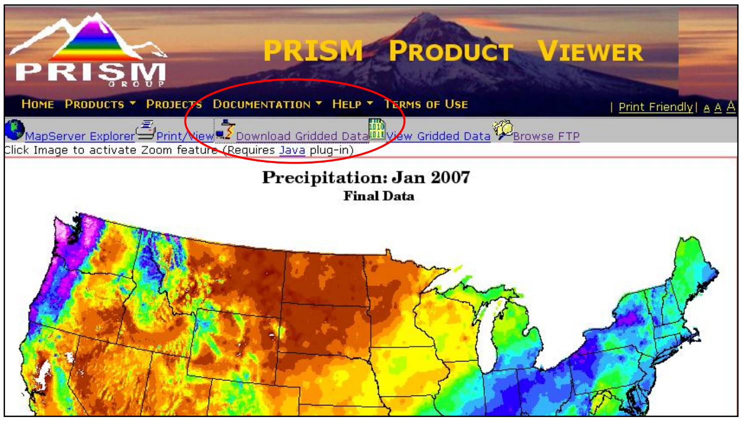

Figure 5. Downloading Gridded Data

All gridded data is gnu-zipped and named the following:

US_PPPP_YYYY.MM.gz

Where

- PPPP is the climate parameter (PPT = precipitation; TMAX = maximum average temperature; TMIN = minimum average temperature; TDMEAN = average dewpoint temperature)
- YYYY is the year
- MM is the month where month 14 is the average of all months for that year.

An alternative way to download a large number of files is to choose “Browse FTP” (Figure 5). Navigate to the years and files of interest.

(4) After downloading monthly data for the years or interest, download 30-year normals for TMAX, TMIN, and PPT.

(5) Once all PRISM data is acquired, produce figures and analyses relevant to the parks by following the instructions in standard operating procedure “*Climate Grid Analysis Toolset – Tools for Assessing Regional Climatological Trends*” (Sherrill and Frakes 2010, NRInfo

RefCode = 2166778). These files are large and when not in use, can be stored on external hard drives or otherwise off-line.

5 - Acquiring SNODAS data

Snow Data Assimilation System (SNODAS) (National Operational Hydrologic Remote Sensing Center [NOHRSC]) integrates surface-based and remotely sensed observations to create a daily 1-kilometer gridded dataset that includes snow depth, SWE, and snow extent (Barrett 2003). The system serves to support hydrologic modeling and analysis, and data are available starting from 2003.

Steps for downloading SNODAS data:

(1) Navigate to the SNODAS ftp site: ftp://sidads.colorado.edu/DATASETS/NOAA/G02158/

SNODAS data is organized and named by date. Data older than one year is compressed into monthly tar files and named SNODAS_YYYYMM.tar (Figure 6). More recent SNODAS data is compressed into a daily tar file and named SNODAS_YYYYMMDD.tar.

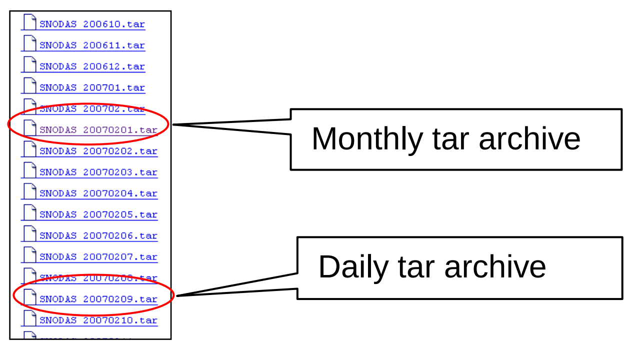

Figure 6. Monthly and Daily tar Archives in SNODAS ftp site

(2) To minimize the number of files to be processed, download only monthly files from the ftp site. Download the following months for the desired water year:

- October
- November
- December
- January
- February
- March
- April
- May
- June

Care should be taken to ensure the proper months are collected for a particular year. The months of October-December fall in the prior calendar year. For example, if the water year is 2007, download October 2006 – June 2007.

(3) Once downloaded, SNODAS data can be processed and analyzed following the instructions in standard operating procedure "*Climate Grid Analysis Toolset – Tools for Assessing Regional Climatological Trends*" (Sherrill and Frakes 2010, NRInfo RefCode = 2166778). These files are large and when not in use, can be stored on external hard drives or otherwise off-line.

6 - Tips for acquiring COOP, SNOTEL, Snow Course and USGS Streamgage data

As of 2010, the NPS IMD accepts requests to acquire, compile, and manage station data from COOP, SNOTEL, Snow Course, and USGS Streamgage systems. These tips demonstrate how to acquire these data on your own in case you need original provider data or if IMD is unable to provide compiled data for requested stations within your required time frame.

During initial data acquisition, multiple years or the complete station history will need to be acquired. In subsequent years, data for individual water year or calendar year may be acquired and combined with past data already acquired stored in the local database. However, since data from previous years or decades may be updated or replaced by the provider, project staff must annually review the source website for indications of changes and updates. Updates and changes can be found in associated metadata files (e.g. station history for COOP network; sensor history and site notes for SNOTEL). If an important update occurs since the data was originally acquired, it may be necessary to download and replace the entire station history data set.

Download methods may differ depending on the requirements and expertise of the project staff and as the providers' online distribution systems change over time. Therefore, the instructions below are guidelines to aid users who will follow current step-by-step directions at each source web site to identify, select, and obtain data. All source websites provide several methods to retrieve a single or multiple stations in a download file. The preferred method will vary by Network depending on the number of stations desired and the most efficient means to retrieve the data. Project staff will document acquisition steps for each transaction to store with metadata in the Protocol database.

Save the file(s) using the appropriate local naming convention or as follows:

[*Source name*]_[*StationID or State*]_[year(yyyy)].txt.

Files in text format are preferred to support data transformations, uploading to other systems, and archiving. *All datasets require formatting prior to importing to a database*.

Project staff should maintain an electronic tracking log for all downloads with the transaction date and the name of the person who conducted the download. The tracking log may be in a database or a simple Microsoft Excel file that is stored with or linked to the downloaded text files. Tracking log review and maintenance activities may be incorporated with annual data quality control procedures.

Steps for downloading COOP data:

(1) Navigate to the COOP station locator website (Figure 7): http://www.ncdc.noaa.gov/oa/climate/stationlocator.html

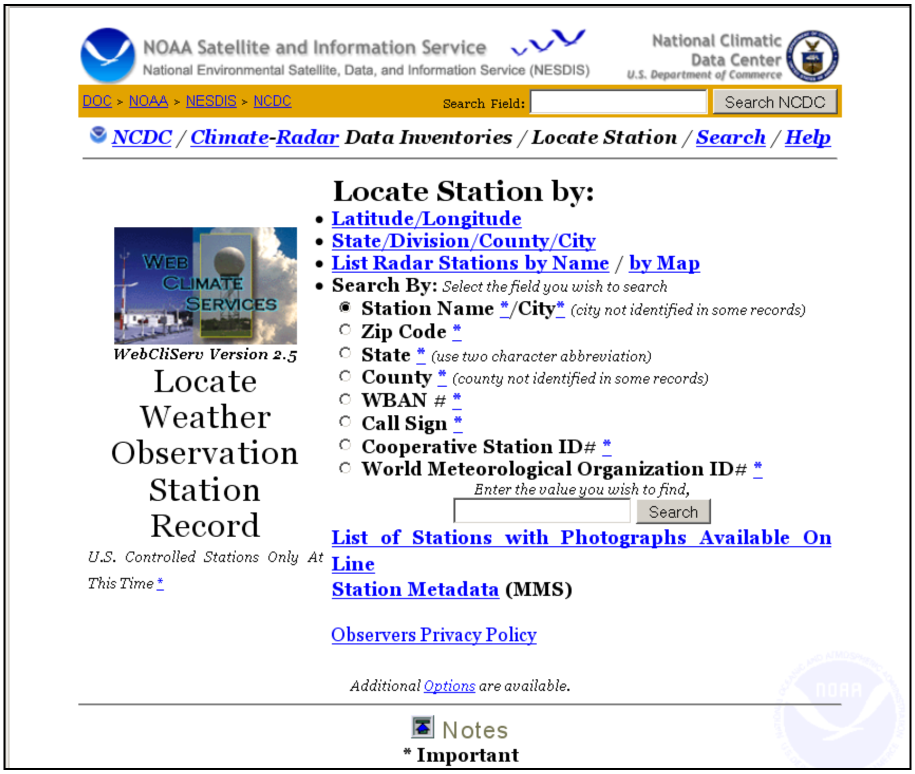

Figure 7. COOP station locator website

(2) Choose station of interest by typing in name in the text box (Figure 7). Hit Search.

(3) From station page, scroll down to choose Daily Surface Data as a DAT (Digital ASCII T Table) file.

(4) Choose Advanced Options.

(5) From the menu provided, choose the time period of interest and parameters. Select output format as “Delimited-Station Names” and “Comma, with data flags”. Hit Continue.

(6) Review the request and check the Inventory Review. Follow directions to download data and save it. At the final stages of data retrieval, NCDC will prompt for an email address to send URL hyperlinks for the user to download the files of interest. On NPS computers, COOP data is free, other users may need to pay a fee.

(7) Once the data files are saved, use the COOP data screener to summarize data (the COOP data screener can be downloaded at: http://yellowstoneecology.com/research/COOP_data.html).

Steps for downloading SNOTEL Station Data:

(1) To obtain SNOTEL data from a station for all years of record or just the most recent year. Navigate to the following website: http://www.wcc.nrcs.usda.gov/cgibin/tab.pl

(2) From that site, one should select the state and then station name. Once a station is selected, Figure 8 shows the option to download all data. Alternatively, you can select to download only certain years.

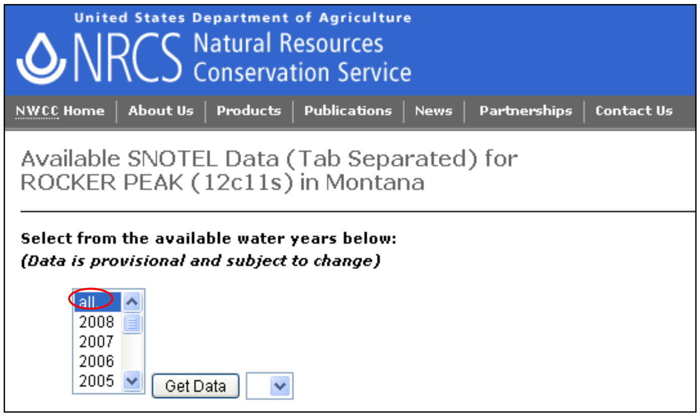

Figure 8. Selecting All Data to Download for One Station

(3) At the present time the screen will provide a download file with the following name if Internet Explorer or the "IE" tab browser option is being used otherwise save the web page as a text file as shown in Figure 9.

The name should only be modified by attaching the date of download, in YYYYMMDD format, after the all. Using the Rocker Peak station in Figure 8 as an example, the file to be saved would be **12c11s_all_20080110.txt**.

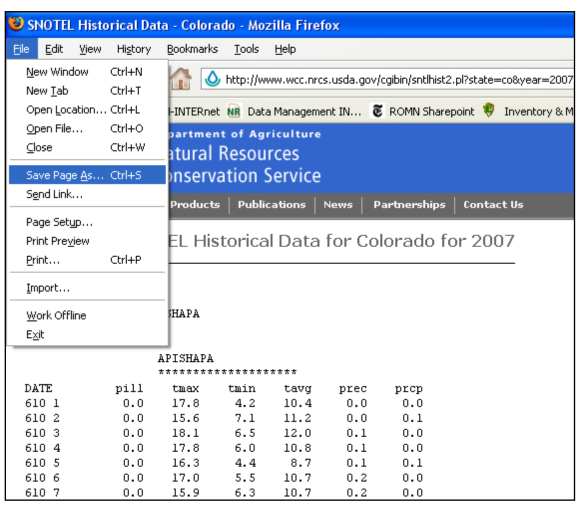

Figure 9. Saving the SNOTEL Web Page as a Text File

Steps for downloading Data from NRCS SnowCourse

(1) When obtaining SnowCourse data, it is easiest to collect all stations and year for each state. This option is available at the following site: http://www.wcc.nrcs.usda.gov/snow/snowhist.html Choose the state of interest.

(2) This will provide a web-based screen of all of the data for that state (Figure 10). The web page should be saved as a text file. Once saved, this file will be renamed to the following: **SnowCourse-SS_YYYYMMDD.txt** Where **SS** is the two-letter state code; and **YYYYMMDD** is the date of download.

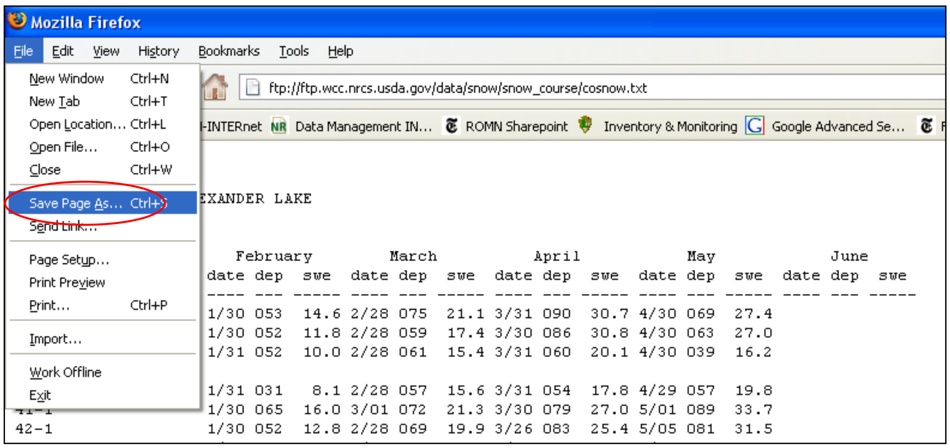

Figure 10. Saving the SnowCourse data as a Text File

Steps for downloading USGS Gage Station Data

USGS Daily Surface Water data is most easily obtained using known Streamgage station identification numbers and a date range that typically spans one or more water years. Discharge (m^3/s) is the primary parameter of interest. Graphs may be obtained from the website. In some cases Networks may be able to use these ready-made graphs for local reporting needs in lieu of generating local data summaries and graphics from downloaded tabular data.

(1) Navigate to http://waterdata.usgs.gov/nwis/dv/?referred_module=sw

(2) Choose Site Name and submit (Figure 11).

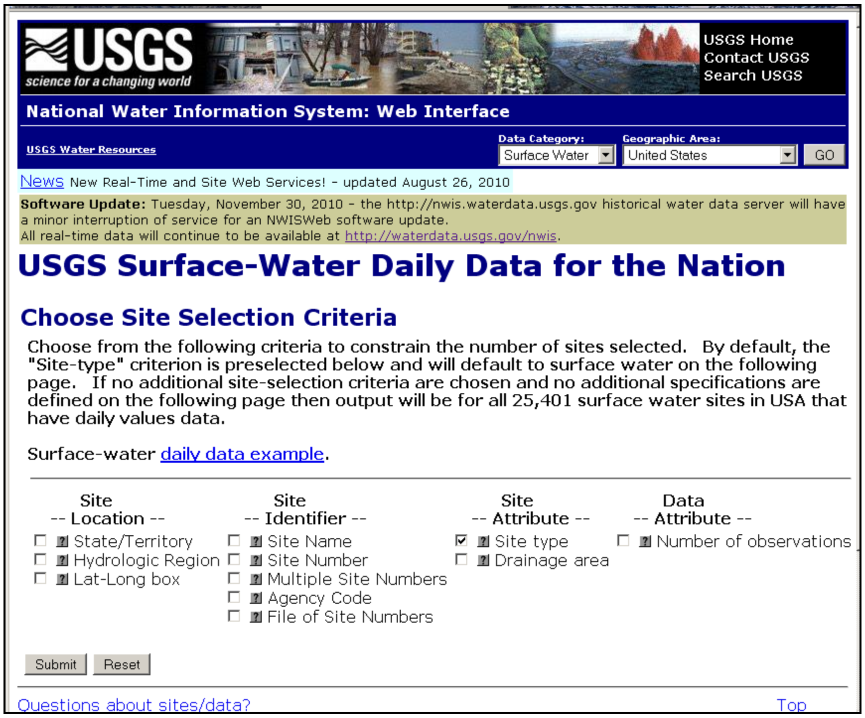

Figure 11. USGS Surface Water Data Web portal

(3) Type Name of Station and scroll down page to hit Submit

(4) Once on station page (Figure 12). Select parameters and dates of interest. Choose either Tab-separated format. Hit Go.

(5) Save webpage with data as text file and name logically with station, dates, and date of download.

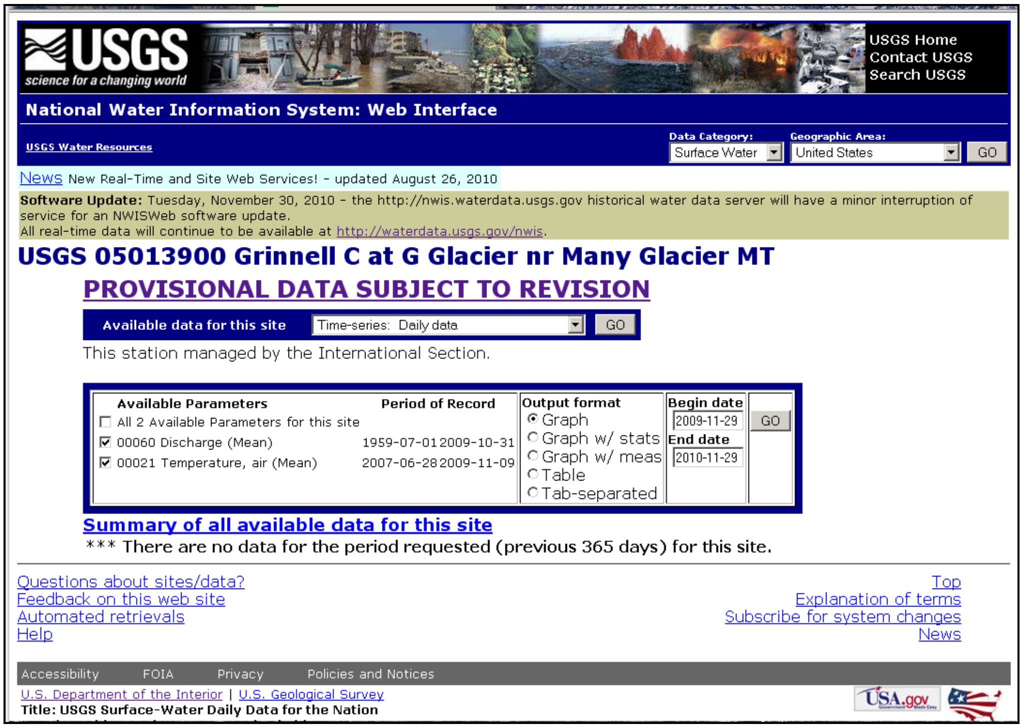

Figure 12. USGS Streamgage data website for a station

7 - Acquiring Original Data Recorded at COOP stations

B-91 Weather Station Records are the original paper forms used by observers in the COOP network and can be downloaded as pdf files. The forms contain all measurements made from one station during one month and may be used to infill missing data or to better QA/QC stations of interest. This step is optional and will not be done by the NPS IMD; instead it is the responsibility of network staff or cooperators. Rather than download all stations, certain stations and months can be targeted when it becomes clear from data analyses and reporting that a large amount of data is missing. If data are corrected based on the forms, a new version of the dataset for that station must be uploaded to the NPS Enterprise Climate Database according to the instructions in the most recent version of standard operating procedure, "*Submitting Data for Upload to the I&M Enterprise Climate Database*" (Frakes 2010b, NRInfo RefCode = 2166928).

Steps to acquire B-91 forms:

(1) Navigate to: http://www7.ncdc.noaa.gov/IPS/coop/coop.html

(2) Choose state of interest (Figure 13), click on NEXT

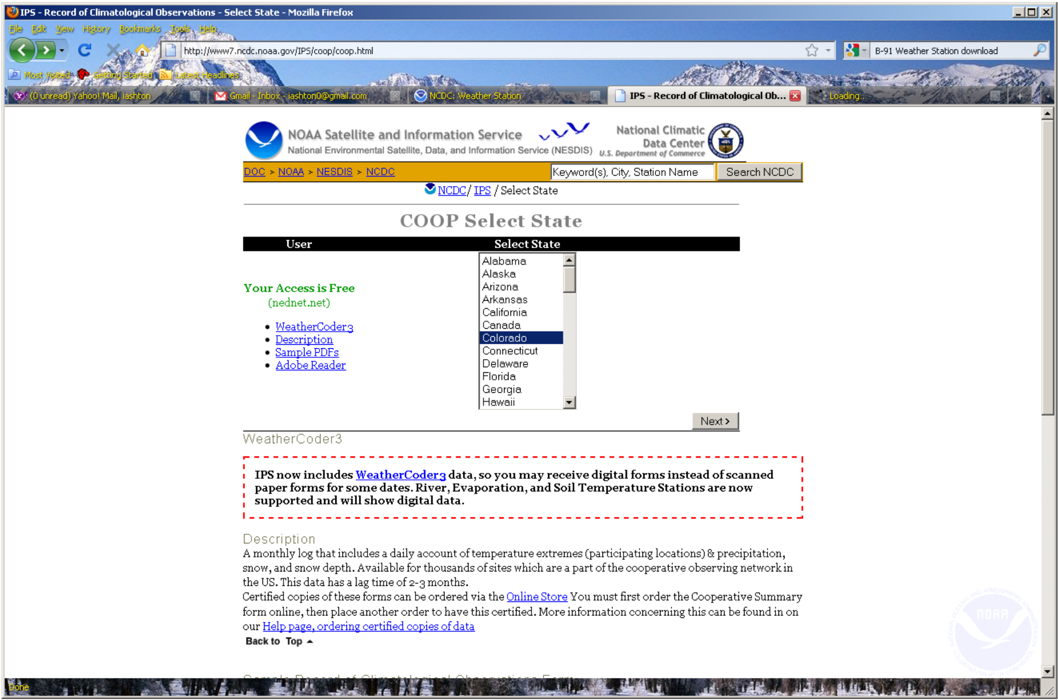

Figure 13. NOAA COOP program B-91 datasheet website

(3) Choose Station of interest, click on NEXT.

(4) Choose Year and Month of interest from list, click on NEXT.

(5) Click on file, it will open as a pdf. Check that it is the correct file and then save file as .pdf and name it “STATION_YEAR_MONTH.pdf”

(6) Compare values from that month with the raw data in the database. Where changes seem prudent, extract the data file from the database, open in a spreadsheet, replace missing values, save file, and follow directions to upload data to database (section 3, above).

(7) In many cases, you will discover that missing values in the database are also missing on the original form. In this case, you cannot correct or infill data. Instead, you can seek guidance from a climatologist in proper methods used to produce models that can estimate values and infill these datapoints. This will take considerable effort and expertise and is only recommended for climate records that are considered high priority for the Networks.

8 - References

Daly, C., Halbleib, M., Smith, J.I., Gibson, W.P., Doggett, M.K., Taylor, G.H., Curtis, J., and Pasteris, P.A. 2008. Physiographically-sensitive mapping of temperature and precipitation across the conterminous United States. International Journal of Climatology, 28: 2031-2064.

Frakes B. 2010. Requesting Essential Parameter Values from COOP, SNOTEL, Streamgage, and Snow Course Data for Acquisition, Compilation, Basic Quality Control, and Distribution by the

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Frakes B. 2010. Submitting Data for Upload to the I&M Enterprise Climate Database. Standard Operating Procedure-2166928. Natural Resource Program Center. National Park Service. Fort Collins CO.

Sherril K, Frakes B. 2010 Climate Grid Analysis Toolset – Tools for Assessing Regional Climatological Treands – Standard Operating Procedure. Unpublished Report-2166778. Natural Resource Program Center. National Park Service. Fort Collins CO.

Rocky Mountain Climate Protocol SOP Database System

Greater Yellowstone & Rocky Mountain Networks: March 2011 version

1 - Change History

Original Version #	Date of Revision	Revised By	Changes	Justification	New Version #
1.0	20100201	L Nelson	Added functional statements; updates to fields		1.01
1.01	20101216	I.Ashton	Reformat, add statement about WASO database		1.02
1.02	20110304	Rob Daley – GRYN	Replaced outdated content with current material from IMD Climate Database	Substantial cooperation between NRPC, IMD, ROMN, GRYN, and SIEN resulted in a a collaborative database system for non-raster data sources.	March 2011

2 - Introduction

A single SQL Server database operated by the NPS Inventory & Monitoring Division (IMD) stores unified parameter data from common providers for stations requested by GRYN, ROMN, and others. The IMD database centralizes data processing functions to include basic quality control and documentation, and provides a simple, stable set of data views from the enterprise database that network users can access directly on client computers for local queries, processing, analysis, and reporting. Versions can be managed and described by users who download, change, and upload a data set. The centralized, consistent, and stable data structure (schema) facilitates transfer of data from the IMD database to the user and back again with improved values resulting from local data quality activities.

An overview of the IMD Climate Database is available here (visited 3/8/2011): http://nrpcsharepoint/gis/gisprojects/GRYNROMN%20Climate%20DB/Forms/AllItems.aspx

Visit the following site for a current schematic view of the IMD Climate database (visited 3/8/2011): http://nrpcsharepoint/gis/gisprojects/GRYNROMN%20Climate%20DB/Forms/AllItems.aspx?RootFolder=%2fgis%2fgisprojects%2fGRYNROMN%20Climate%20DB%2fSOPs&FolderCTID=&View=%7b801C31EE%2d251C%2d43CF%2d85BE%2d4E5B12E0F6A3%7d

A current list of data retrieval, summary, and analysis functions is available in SOP 'Connecting to the I&M Enterprise Climate Database for the Purpose of Data Retrieval, Summary and/or Analysis'(https://nrinfo.nps.gov/Reference.mvc/Profile?code=2167699).

List of Tables in the IMD Climate Database (as of March 4, 2011)

- INP2300FCSGUMO6\GIS_Working_Data (SQL Server 10.0.2531 - climate_reader)
  - Databases
    - System Databases
    - Database Snapshots
    - D_Climate_DB
      - Database Diagrams
      - Tables
        - System Tables
        - dbo.DataLoadAttempt
        - dbo.DataLoadAttemptResult
        - dbo.DateCrosswalk
        - dbo.Flag
        - dbo.Location
        - dbo.Note
        - dbo.Observation
        - dbo.ObservationFlag
        - dbo.Parameter
        - dbo.ParkLocation
        - dbo.Source
        - dbo.Station
        - dbo.StationList
        - dbo.StationListStation
        - dbo.StationListStationUnits
        - dbo.TemperatureBins
        - dbo.Unit
        - dbo.User
        - dbo.Version
        - load.StationRequest
        - load.StationRequestUnit
        - Temp.COOP_Stations
        - Temp.DataStaging
        - Temp.GRYN_Stations
        - Temp.ROMN_Stations
        - Temp.SNOTEL_Stations
        - Temp.SNOTEL_Stations_20101008
        - Temp.SnowCourse_Stations
        - Temp.Station
        - Temp.USGS_Stations
        - Temp.WxStationRequest

List of Views in the IMD Climate Database (as of March 4, 2011)

- INP2300FCSGUMO6\GIS_Working_Data (SQL Server 10.0.2531 - climate_reader)
  - Databases
    - System Databases
    - Database Snapshots
    - D_Climate_DB
      - Database Diagrams
      - Tables
      - Views
        - System Views
        - qa.StationRequest_StationDataNotLoaded
        - qa.StationsWithLocationEarlierStartDateThanStationStartDate
        - qa.StationsWithNoLocation
        - viewer.AllowableUserParameters
        - viewer.ExcludedObservations
        - viewer.IncludedObservations
        - viewer.LastLoadAttemptPerStation
        - viewer.qa_ObservationValueOutsideExpectedRange
        - viewer.qa_TminGreaterThanTmax
        - viewer.StationRequestLoadProgress
        - viewer.StationsInDatabase
        - viewer.vBasicSelection
        - viewer.vBasicSelectionWithFlags
        - viewer.VersionInfo
        - viewer.vFlagLists

List of Table-valued Functions in the IMD Climate Database (as of March 4, 2011)

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        - viewer.GetMonthlyTotalDepartureFromReferencePeriodForVersion
        - viewer.GetMonthlyTotalForVersion
        - viewer.GetMonthlyTotalForVersionForReferencePeriod
        - viewer.GetMonthlyTotalForVersionForTimePeriod
        - viewer.GetNumDaysValueWasLteOrGteForPeriod
        - viewer.GetObservationGapsForVersion
        - viewer.GetObservationGapsForVersionForTimePeriod
        - viewer.GetTemperatureFrequenciesByBinsForDateRange
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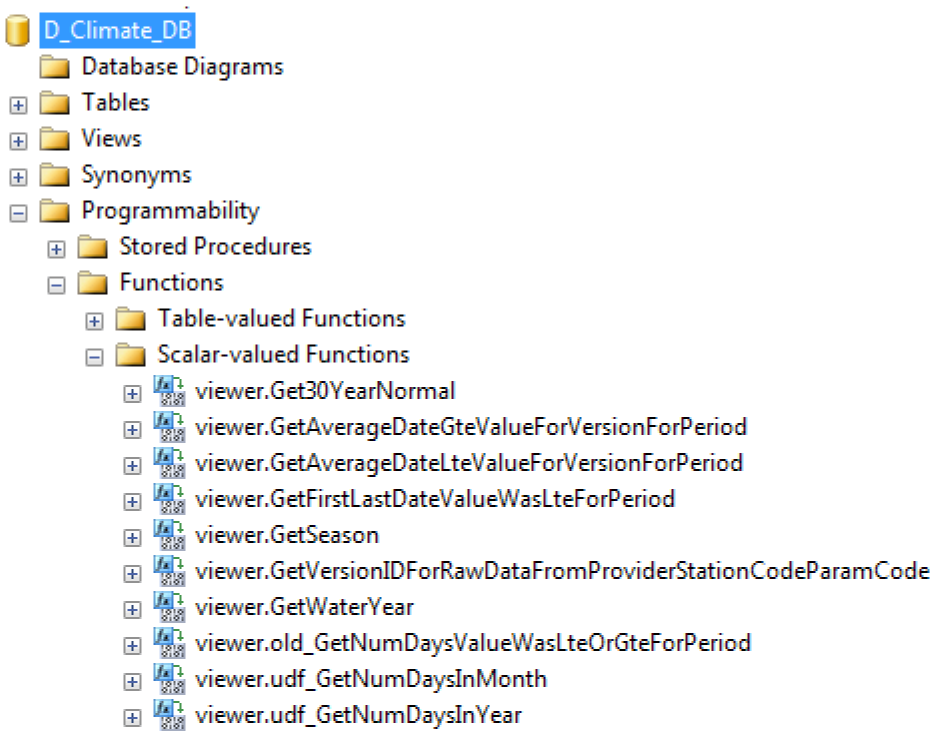
List of Scalar-valued Functions in the IMD Climate Database (as of March 4, 2011)



Rocky Mountain Climate Protocol SOP Defining Climate Zones

Greater Yellowstone & Rocky Mountain Networks: March 2011 version

1 - Change History

Revision History Log

Previous Version #	Revision date	Author	Changes made	Section and paragraph	Reason for change	New Version #
0.1	6-20-10	I.Ashton	Added text from Tercek ROMN zonation report	Throughout	Clarify methods	1.0
1.0	March 4, 2011	Rob Daley – GRYN	Minor clarifications based on comments from original author Mike Tercek	Various	Scheduled review	March 2011

2 - Introduction

Here we outline the process and data requirements for defining within-network climate reporting zones or units. The goal of this procedure is to define groups of weather stations in and near park units that have (1) similar average seasonal (month to month) patterns of temperature and precipitation, and (2) similar long-term patterns of variability over the period 1895- 2008. An additional analysis of snow cover timing is used to determine whether there is stratification among weather stations according to elevation. Additional information on these procedures is provided in Kittel et al. 2010. The purpose of this analysis is to identify distinct zones with recognizable, internally-consistent temporal dynamics. An important criterion is that distinctions in regional dynamics be interpretable in terms of climatological processes.

These within-network climate zones will provide strata for climate analysis and reporting in both the *Annual Status* and *Variability and Trends* reports, and are generally referred to as reporting units in the RMCP. This foundational analysis should be performed early in protocol implementation, so that the reporting unit delineations are available to use for the initial *Annual Status Report*. Averaging weather observations across an entire park would be of little value because it would obscure much of the spatial (place to place) variability among regions. The analysis presented here defines climate zones with consistent seasonal and temporal dynamics. These zones will be treated as reporting units in annual climate status reports. Three statistical techniques were used: (1) Cluster analysis of seasonal weather station data (temperature and precipitation), (2) Principal Components Analysis of long-term monthly variability in temperature and precipitation, and (3) Analysis of snow cover timing to define elevation-based stratification of stations.

3 - Cluster Analysis

3.1 Overview

The cluster analysis can be divided into three general steps:

1. Hierarchical agglomerative cluster analysis is performed on weather station data. The variables of interest are 1971-2000 monthly normals for mean temperature (Tmean), diurnal temperature range (DTR), and precipitation.
2. Average seasonal pattern (monthly values for each climate parameter) is determined for each climate zone suggested by the cluster analysis.
3. Spatial correlation maps are produced. These maps show the degree of correlation between grid cells in the PRISM data layer and the monthly values calculated in step 2. This delineates regions that have affinity with each cluster of weather stations.

3.2 Download and Format the Data (COOP, SNOTEL and PRISM data)

Monthly average maximum temperature (Tmax), minimum temperature (Tmin) and precipitation data can be downloaded for the period 1971 – 2000 from the websites of the Western Regional Climate Center (WRCC) (www.wrcc.dri.edu), the Natural Resources Conservation Service (NRCS) (www.wcc.nrcs.usda.gov), and the Parameter-elevation Regressions on Independent Slopes Model (PRISM) climate group (http://www.prism.oregonstate.edu/). For each weather station, Diurnal Temperature Range (DTR) and mean temperature (Tmean) are calculated for each month from Tmax and Tmin. Tmax and Tmin often vary at different rates, making them both important to the analysis, but DTR and Tmean usually show lower correlation with each other, which gives greater power to cluster analysis.

For COOP stations, NCDC monthly normal data are incorporated into the analyses directly from the WRCC web site. In contrast, only precipitation data from the NRCS web site are used because SNOTEL stations often have poor quality temperature data or missing values that make it impossible to calculate accurate 1971-2000 normals (Kittell et al. 2010). In order to replace the missing temperature data, Tmax and Tmin 1971 – 2000 normals are extracted from the 800m PRISM grid cell occupied by each SNOTEL station. PRISM data do not have the same problems as individual SNOTEL temperature data because the values for each grid cell are interpolated from a network of surrounding stations.

To do this, first compile a list of all the COOP and SNOTEL weather stations in the area of interest, their latitude and longitude coordinates, elevations, and metadata. The analysis will be based on station normals for Tmean, DTR, and precipitation for all stations with 30-year normals available within network domains. Use precipitation data from SNOTEL stations, but not temperature data. Use both precipitation and temperature data from COOP and PRISM.

Download 1971- 2000 monthly temperature and precipitation normals for each weather station (a different 30-year normal period can be used if it results in more stations being available for inclusion in this analysis). DTR and Tmean are derived from minimum and maximum temperature normals.

To download station data, go to the web page for each station, and obtain text versions of the normals. Data need to be downloaded from COOP, SNOTEL and PRISM websites, as described below.

3.2.1 COOP Station Data

COOP data are available at: http://www.wrcc.dri.edu/summary/Climsmwy.html.

Select the station name from the list on the left side of the screen. Click on the station name to bring up summary data and a link to the 1971-2000 normals (see Figure 1). Click on the link to the normals, and then copy and paste the data into a spreadsheet (e.g. Microsoft Excel).

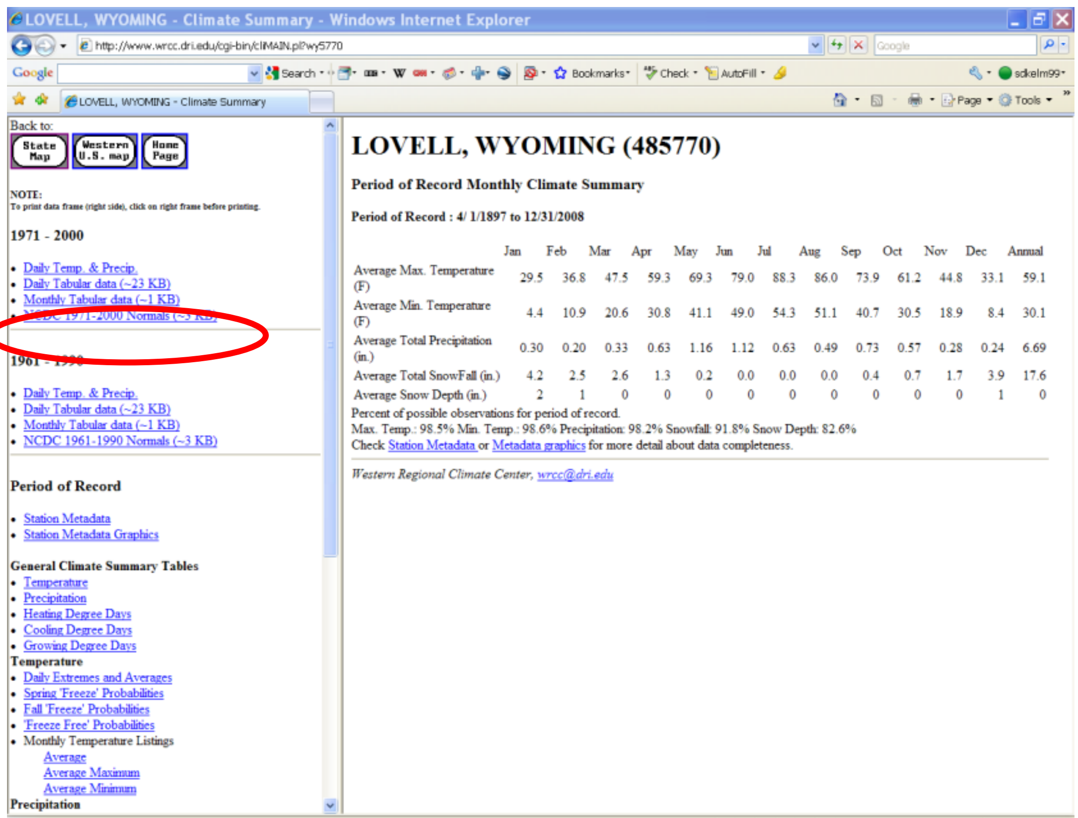


Figure 1. Selecting 1971-2000 normals for the Lovell COOP weather station.

3.2.2 SNOTEL Station data

To obtain SNOTEL 1971-2000 normals for precipitation, go to the following website:

http://www.wcc.nrcs.usda.gov/snow/snotel-precip-data.html

Click on "Monthly Historical Precipitation Data Tables" and select a state and then a station. The 1971-2000 normals are given at the bottom of the file.

DTR and Tmean must be derived from minimum and maximum temperature normals. Ultimately, there will be 36 variables for each station: 12 monthly precipitation, 12 monthly Tmean, and 12 DTR variables. Allow >20 hours to complete these steps.

SNOTEL stations:

http://www.wcc.nrcs.usda.gov/cgibin/tab.pl

3.2.3 PRISM Gridded data

Obtain 1971 - 2000 precipitation, average monthly maximum temperature (Tmax), and average monthly minimum temperature (Tmin) normals for each month from the PRISM web site (http://www.prism.oregonstate.edu/). This will require downloading 36 files, with each file being 15 - 18mb. Once they are on your hard drive, re-name them so that they have a .txt extension. All files will need to be converted before analysis. To convert these txt files into GIS layers for your area:

- Open a blank map in ArcGIS
- In the toolbox, use Conversion tools > to raster > ASCIItoRaster to convert the text files into raster images.
- Use the tool in Data Management > Raster > Clip to clip out the area of interest. Be sure that your area of interest extends at least 40km beyond the boundaries of all national parks in your network.

PRISM files cover the entire lower 48 states. In order to make the calculations in the following steps manageable, it is essential to complete this clipping step or your computer will take an unacceptable amount of time to produce your climate maps. The file conversion and clipping steps will need to be repeated for each PRISM file.

Next re-project your PRISM raster files (36 times, once for each file) into the UTM coordinate system using the tool found in

Data Management Tools > Raster > Project

- If desired, you can create an attribute table for each raster file with the Build Raster Attribute tool.

3.3 Perform the Cluster Analysis Using R

Use R to do the cluster analysis of 1971-2000 weather station normals following the methods of Fovell and Fovell (1993) and Unal et al. (2003). This method is designed to cluster weather stations according to similarity of their intra-annual variability, e.g. monthly patterns of precipitation. Since the goal of the cluster analysis is to group weather stations according to their similarity in seasonal patterns, regardless of the absolute magnitude of the observations or differences among stations in the amount of seasonal variance, the data were standardized as z-scores. For each weather station separately, the annual averages for precipitation, DTR, and Tmean are subtracted from their respective monthly values and the results were divided by the annual standard deviations for each variable. This produces a data matrix of 36 values for each weather station, with 12 monthly standardized values each for precipitation, DTR, and Tmean.

Three criteria are used to determine the number of climate zones for a park unit:
1. Both Ward's and Average clustering algorithms are used and the results are compared (Unal et al. 2003). If a cluster of weather stations appeared unchanged in dendrograms produced by both algorithms, it is retained. If a cluster contains different weather stations in Ward's vs. Average clustering, it is treated as a polytomy (unstructured group) and a larger cluster of stations containing both the polytomy and the cluster of stations most similar to it are examined. Successively larger clusters of stations are examined until groups with the same membership in both Ward's and Average dendrograms are found. This procedure defines the minimum size of the station clusters that were used as zones.

2. Confidence levels were assigned to each cluster of stations with bootstrapping (Suzuki and Shimodaira 2006). Ten thousand pseudo-replicates of the data set were produced and the nodes in the final dendrogram were labeled with the percentage of pseudo-replicate dendrograms that contained each cluster. Clusters with less than 80% bootstrap support were joined with neighboring clusters.

3. The results for each park unit were inspected for groups of stations that both appeared together in the cluster analysis and varied similarly (loaded on the same PCs) in the Principal Components Analysis. If such groups were found, they were defined as climate zones even if they did not meet the second criterion.

The cluster analysis was performed with the R scripting language (R development core team 2009) following these steps:

- Combine Tmean, DTR, and precipitation weather station normals into a single file. Station names should be the first column of the file. Monthly normals should appear as additional columns to the right. DTR and Tmean must be calculated from the Tmax and Tmin data prior to analysis.

- A suggested R script is provided in the file "R_Cluster_Analysis.doc" (available on the RMCP site for tools at http://imnetsharepoint/ROMN/Protocols/RockyMountainClimate/DraftProtocol/Tools).

- Prior to using this script, the data for each station should be standardized by subtracting the annual mean from each monthly value and dividing by the standard deviation of the station’s values. Even though all three climate parameters are contained in a single file, this standardization should be performed separately for each (Tmean, DTR, precipitation).

- In the R script, change the clustering method to either "Ward" or "average" and compare the results. See Figure 2 for example results.

- In the R script, the value assigned to K controls the number of zones that will be delineated by red boxes in the final dendrogram (Figure 2). See the comments in the R script for additional detail.

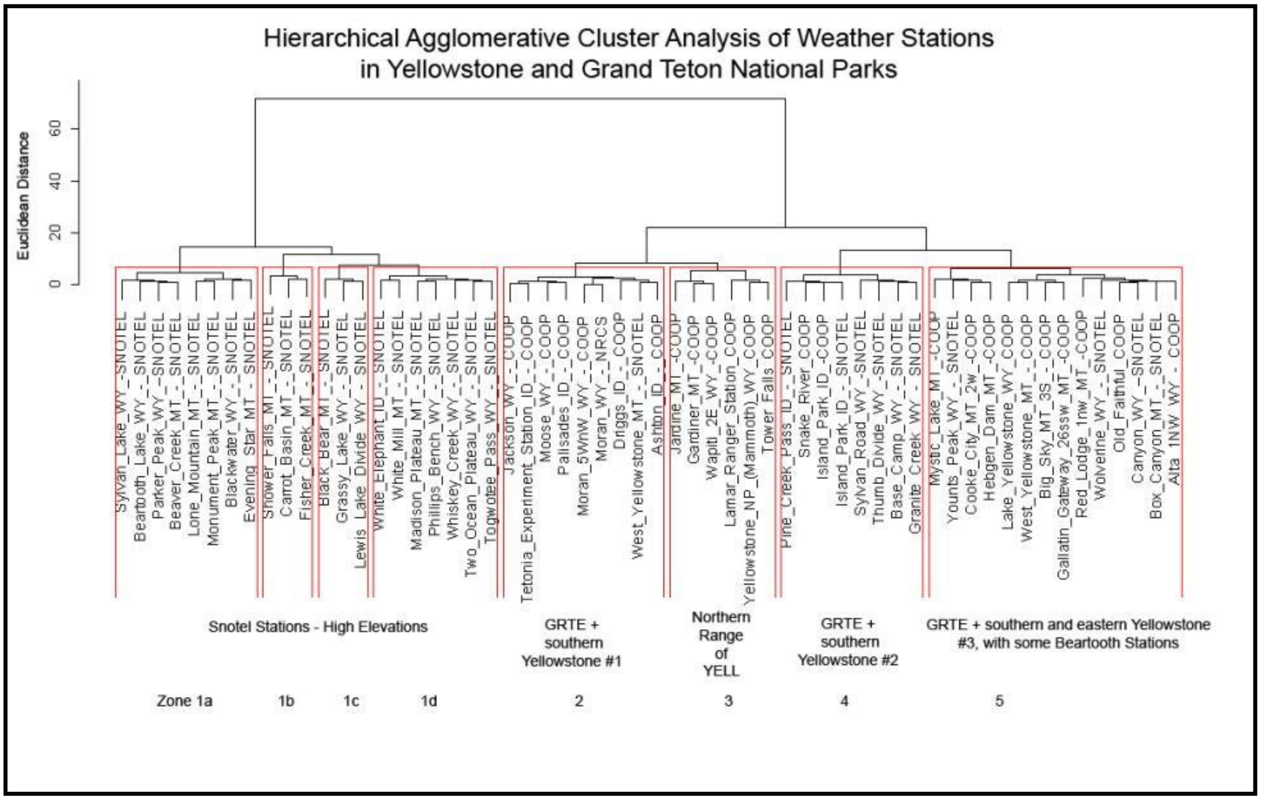


Figure 2. Preliminary cluster analysis results for precipitation data from Yellowstone and Grand Teton National Parks. Results suggest the creation of 5 climate zones for this area. The details of the methods have changed slightly since this preliminary analysis was performed. Consequently, the final results for the Greater Yellowstone Network may differ from those shown here.

3.4 Plot the Locations of Weather Stations Defined by Each Zone

The next step is to plot the locations of the weather stations defined by each zone in ArcGIS. Create a map showing the geographic location of each weather station in the cluster dendrogram. Use PRISM data as a background. Check the results at this stage to make sure they appear correct or meaningful before proceeding to the time-consuming next step. At this stage of the analysis it is important to evaluate the degree to which the zones proposed by the cluster analysis overlap. Other important considerations include the geographic cohesiveness of the proposed zones and their elevational stratification. Do the stations in each zone appear in discrete clusters on the map or do they form a “shotgun” or random pattern? Does one of the clusters contain only high elevation stations?

While performing this step, it may be useful to make climographs (graphs of 1971-2000 normals) for each station and place them on the map. This will help determine whether stations within each zone have similar season patterns of temperature and precipitation. If stations within a zone do not appear to have similar patterns (e.g., a majority of precipitation in either summer or winter) the cluster analysis may contain errors.

A correlation map is created as an estimate of the geographical area represented by the weather stations in each climate zone. The monthly normals from the cluster analysis data set are averaged across all the weather stations in each newly defined climate zone, to produce 36 monthly values (12 months each for DTR, Tmean, and precipitation). Pearson's correlation coefficients are then calculated between the 36 monthly zone averages and the 36 corresponding values associated with each 800m grid cell in the PRISM 1971 – 2000 monthly normal data set. The correlation values for each climate zone are converted into graphical raster files and are mapped. Grid cells are either colored or not, depending on whether they have correlation values above a threshold value for each zone. Cells with correlations falling below a specific threshold for all climate zones are left uncolored. For each park unit, several alternative maps can be produced with greater or smaller correlation thresholds. A final correlation threshold is chosen based on its ability to provide minimal geographic overlap among zones. Lower correlation thresholds create geographically larger zones and greater overlap. Higher correlation thresholds produce isolated climate zones with large intervening white, unclassified areas. The use of different thresholds for each park unit is justified because the correlation maps are merely a technique for illustrating the *approximate* geographic area associated with each group of weather stations. There are at least two factors that affect the degree of similarity among climate zones, and consequently the correlation threshold that must be used to produce contiguous but nonoverlapping zone boundary estimates. First, parks that have a larger number of weather stations, and consequently greater station density, provide better coverage for the geographic areas that they represent and allow for the use of higher correlation thresholds. In contrast, areas with relatively poor weather station density will have climate zones with lower correlation to the weather stations within them. Second, if the zonation analysis is conducted on a relatively small geographic area, there will likely be greater similarity among the zones. As a result, some grid cells are likely to have relatively high correlations with more than one zone, and a higher correlation threshold would be needed in order to assign only one color to each grid cell. Because of the potentially high degree of overlap among zones, correlation maps are not calculated for the smaller parks units. A detailed list of methods follows.

3.5 Create a Correlation Map

1. The first step in creating the correlation map is to convert your PRISM raster data into points and export the values for each point on the map into a text file. You will need these values in order to make the correlation calculations that go into the final map of climate zones. The steps to convert the PRISM raster data to points are as follows:

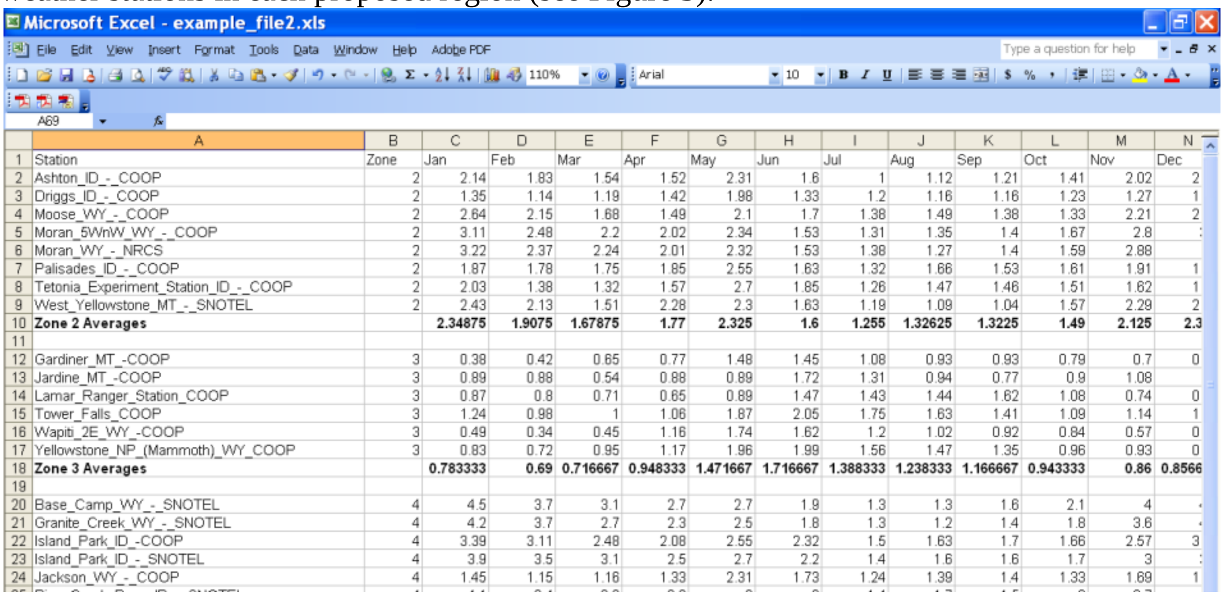
- In ArcGIS, use the "RasterToPoint" tool to create a grid of points, with one point at the center of each raster cell. Use one of your PRISM raster files as the input layer. Be certain that you have clipped the layer to a reasonable size before you do this

- Use the ArcGIS tool "extract values to points" to extract the January precipitation PRISM data into a new shapefile. Use the layer that you created in the previous step as the "input feature." In the attribute table of the new shapefile, change name of the column labeled "Rastervalu" to “January.”

- Repeat the previous step for every PRISM layer.

- When you are done, the attribute table of your target shapefile should have 36 values for each grid cell on the map (12 months each for Tmax, Tmin, and precipitation).
- Export the attribute table containing the data to a text file.
- Calculate DTR and Tmean from Tmax and Tmin for each grid cell using SPSS or another tool that can handle a large data file.

2. Calculate the average temperature, precipitation, and DTR values for each month across all the weather stations in each proposed region (see Figure 3).



	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Station	Zone	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2	Ashton_ID_-_COOP	2	2.14	1.83	1.54	1.52	2.31	1.6	1	1.12	1.21	1.41	2.02	2
3	Driggs_ID_-_COOP	2	1.35	1.14	1.19	1.42	1.98	1.33	1.2	1.16	1.16	1.23	1.27	1
4	Moose_WY_-_COOP	2	2.64	2.15	1.68	1.49	2.1	1.7	1.38	1.49	1.38	1.33	2.21	2
5	Moran_5WnW_WY_-_COOP	2	3.11	2.48	2.2	2.02	2.34	1.53	1.31	1.35	1.4	1.67	2.8	
6	Moran_WY_-_NRCS	2	3.22	2.37	2.24	2.01	2.32	1.53	1.38	1.27	1.4	1.59	2.88	
7	Palisades_ID_-_COOP	2	1.87	1.78	1.75	1.85	2.55	1.63	1.32	1.66	1.53	1.61	1.91	1
8	Tetonia_Experiment_Station_ID_-_COOP	2	2.03	1.38	1.32	1.57	2.7	1.85	1.26	1.47	1.46	1.51	1.62	1
9	West_Yellowstone_MT_-_SNOTEL	2	2.43	2.13	1.51	2.28	2.3	1.63	1.19	1.09	1.04	1.57	2.29	2
10	**Zone 2 Averages**		**2.34875**	**1.9075**	**1.67875**	**1.77**	**2.325**	**1.6**	**1.255**	**1.32625**	**1.3225**	**1.49**	**2.125**	**2.3**
11														
12	Gardiner_MT_-COOP	3	0.38	0.42	0.65	0.77	1.48	1.45	1.08	0.93	0.93	0.79	0.7	0
13	Jardine_MT_-COOP	3	0.89	0.88	0.54	0.88	0.89	1.72	1.31	0.94	0.77	0.9	1.08	
14	Lamar_Ranger_Station_COOP	3	0.87	0.8	0.71	0.65	0.89	1.47	1.43	1.44	1.62	1.08	0.74	0
15	Tower_Falls_COOP	3	1.24	0.98	1	1.06	1.87	2.05	1.75	1.63	1.41	1.09	1.14	1
16	Wapiti_2E_WY_-COOP	3	0.49	0.34	0.45	1.16	1.74	1.62	1.2	1.02	0.92	0.84	0.57	0
17	Yellowstone_NP_(Mammoth)_WY_COOP	3	0.83	0.72	0.95	1.17	1.96	1.99	1.56	1.47	1.35	0.96	0.93	0
18	**Zone 3 Averages**		**0.783333**	**0.69**	**0.716667**	**0.948333**	**1.471667**	**1.716667**	**1.388333**	**1.238333**	**1.166667**	**0.943333**	**0.86**	**0.8566**
19														
20	Base_Camp_WY_-_SNOTEL	4	4.5	3.7	3.1	2.7	2.7	1.9	1.3	1.3	1.6	2.1	4	
21	Granite_Creek_WY_-_SNOTEL	4	4.2	3.7	2.7	2.3	2.5	1.8	1.3	1.2	1.4	1.8	3.6	
22	Island_Park_ID_-COOP	4	3.39	3.11	2.48	2.08	2.55	2.32	1.5	1.63	1.7	1.66	2.57	3
23	Island_Park_ID_-_SNOTEL	4	3.9	3.5	3.1	2.5	2.7	2.2	1.4	1.6	1.6	1.7	3	
24	Jackson_WY_-_COOP	4	1.45	1.15	1.16	1.33	2.31	1.73	1.24	1.39	1.4	1.33	1.69	1

Figure 3. Example data file showing calculation of average values for each proposed region.

3. Calculate the correlation between each grid cell on the map and the monthly averages produced by step 2 above. It is important to realize that the correlation calculated here is (for each map cell) between the 12 monthly values for 3 parameters (Tmean, precipitation and DTR) extracted from the PRISM layers and the monthly average values calculated for each zone in step 2. These calculations must be repeated for each proposed climate zone. For the GRYN analysis, there were 219,858 grid cells on the map and 5 proposed climate zones, so a total of 219,858 X 5 = 1,099,290 correlations were calculated. Microsoft Excel cannot handle a file this large, so a different tool, such as SPSS should be used. Enter the formula for Pearson's correlation into the final column, producing the values as shown in Regionalization_Example_Data_Format.pdf (available on the RMCP site–for tools). There was a similar file for each proposed climate zone.

Save the correlations as a tab-delimited text file. Make sure it has a *.txt extension.

4. Perform the following steps to import the correlations from step 3 back into ArcGIS and generate raster maps from them.

   Open a blank map in ArcMap and add the point shapefile that you created in step 1.

On the editor toolbar, click "Start Editing" and choose the name of the shapefile in the pop-up dialog.

“Join” the tab-delimited text file created in step 3 to the attribute table of the shapefile. Use the "PointID" attribute as the join field for both the shapefile and the text file. NOTE: It is important to ensure that the shapefile has not been edited in any way since you extracted the values from it. If the shapefile has been edited, the PointID fields will no longer correspond to the correlation values that you calculated in step 3.

Use the “PointToRaster” tool to convert the point shapefile into a raster image. Choose the column containing your correlation values as the "value field." Repeat this step for each set of correlations, generating a separate raster map for each proposed climate zone. NOTE: For GRYN data, it took the computer approximately 6 hours to convert the point data into a raster image (using a 2.3 ghz intel Pentium M laptop with 2 gb of ram). Do not worry if the computer appears to freeze for several hours. Be patient. If you have 5 proposed zones, it will take the computer 6 hours per map X 5 = 30 hours of continuous run time to make the calculations necessary to produce your climate maps.

5. Plot your new raster maps together and determine how much they overlap. As a first step, it is useful to make all the layers semi-transparent. For example, if there are 5 zone maps, make each one display with 20% (1/5) opacity.

4 - Principal Components Analysis

4.1 Introduction

The cluster analysis was designed to group weather stations according to similarities in their INTRA-annual variability (Kittel et al. 2010). In contrast, the Principal Components Analysis (PCA) described here is designed to group weather stations through an ordination of INTER-annual (year to year) and multi-decadal variability patterns. To do this, it looks at a single climate parameter (e.g., monthly temperature and precipitation analyzed separately) over a long time period. For example, the preliminary GRYN PCA included data from 9 weather stations for every month during a 76 year time period (1931-2006). Alternatively, data for a larger number of stations may be extracted from PRISM layers. In the latter case, the values for each month would be taken from the grid cell nearest each weather station of interest.

Data for the Principal Components Analysis (PCA) are extracted from 1895-2008 monthly, 800m resolution, gridded data produced by the PRISM climate group (Daly et al. 2000, http://www.prism.oregonstate.edu/). Monthly time series for Tmax, Tmin, and precipitation are extracted from the grid cells occupied by each weather station. Tmean for each station is calculated from Tmax and Tmin. Each precipitation and Tmean time series is split into separate summer (June, July, August) and winter (December, January, February) time series. This results in four separate data sets for analysis: winter precipitation, summer precipitation, winter Tmean, and summer Tmean. PRISM data have two advantages over raw weather station data. First, since PRISM data for each grid cell are interpolated by using a network of surrounding stations it is possible to extract time series that extend further back in time than the individual weather stations themselves. Second, PRISM data have been quality checked and peer-reviewed. As a result, they are less prone to biases such as urban heat island effects, station moves, instrument changes, and incompleteness of record that make long-term analyses of raw weather station data difficult (Daly et al. 2000, 2001).

S-mode PCA is performed using methods adapted from Serrano et al. (1999) and Comrie and Glenn (1998). The data matrix has weather stations occupying the columns and months for a single variable, e.g. precipitation, in the rows. A standard PCA scatter plot of this data will show the separation of months along the first two principal components (PCs), so differences among weather stations instead is interpreted from the loadings. The data are natural-log transformed, scaled (performed on the correlation rather than the covariance matrix), and detrended with linear regression prior to analysis. Varimax rotation is used to prevent the shape of the geographic area being analyzed from affecting the results (Buell 1975, Serrano et al. 1999). Scree plots are examined to determine how many principal components to retain. The data are preprocessed with a script written in Scientific Python (www.scipy.org), and the PCA is performed with the R scripting language (R development core team 2009). The detailed steps follow below.

The procedure described here should be distinguished from studies that used PCA as a data reduction method that precedes cluster analysis (e.g., Fovell and Fovell 1993). In the latter case, R-mode PCA is used to simplify a large number of diverse climate parameters into a smaller set of components, and it is these simplified components that feed into the cluster analysis that ultimately defines the climate zones. For more information on the different modes of PCA, consult: http://faculty.chass.ncsu.edu/garson/PA765/factor.htm

4.2 4.2 Obtain necessary data and screen for errors

Download monthly temperature, precipitation, and dew point data for the period of record from at least one station (preferably more) in each of the climate zones defined by the cluster analysis. Alternatively, data may be extracted from PRISM data by collating the data from the grid cell nearest each weather station.

Details for obtaining station data:
Data from the United States Historical Climatology Network (USHCN) is strongly preferred over National Climatic Data Center (NCDC) station data because it has already been quality-checked. Check the USHCN web site to see which stations are available in your area of interest: http://cdiac.ornl.gov/epubs/ndp/ushcn/newushcn.html

Data from the USHCN web site is formatted like the file “USHCN_example.csv”in Regionalization_Example_Data_Format.pdf , which is located on the RMCP site for Tools and shown in Figure 5.

Microsoft Excel - USHCN_example.csv [Read-Only]

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Source: CN Wil	MJ Menne	RS Vose	DR Easterli	NOAA	Natio	Asheville	NC								
2	State_id	YEAR	Month	CPRCP (in)	CPRCPS (	CRPF	CRPRCPS (in)	PRCP (in)	RPRCP (in)	Season_prcp	TAVE (F)	TAVE_f	TMAX (F)	TMAX_f	TMIN (F)	TMIN_f
3	'489905'	1895	11	.	.	16.4	1.74	.	1.3	'1895-96'	.	'50E'	.	'50E'	.	'50E'
4	'489905'	1895	12	.	.	17.6	3.03	.	1.29	'1895-96'	.	'50E'	.	'50E'	.	'50E'
5	'489905'	1896	1	.	.	2.21	5.24	.	2.21	'1895-96'	.	'50E'	.	'50E'	.	'50E'
6	'489905'	1896	2	.	.	4.28	7.31	.	2.07	'1895-96'	.	'50E'	.	'50E'	.	'50E'
7	'489905'	1896	3	.	.	6.9	9.93	.	2.62	'1895-96'	.	'50E'	.	'50E'	.	'50E'
8	'489905'	1896	4	.	.	8.19	11.22	.	1.29	'1895-96'	.	'50E'	.	'50E'	.	'50E'
9	'489905'	1896	5	.	.	12	15.07	.	3.85	'1895-96'	.	'50E'	.	'50E'	.	'50E'
10	'489905'	1896	6	.	.	12.8	15.8	.	0.73	'1895-96'	.	'50E'	.	'50E'	.	'50E'
11	'489905'	1896	7	.	.	14.9	17.89	.	2.09	'1895-96'	.	'50E'	.	'50E'	.	'50E'
12	'489905'	1896	8	.	.	15.2	18.26	.	0.37	'1895-96'	.	'50E'	.	'10E'	.	'10E'
13	'489905'	1896	9	.	.	16.3	19.36	.	1.1	'1895-96'	.	'50E'	.	'10E'	.	'10E'
14	'489905'	1896	10	.	.	16.4	0.06	.	0.06	'1896-97'	.	'50E'	.	'10E'	.	'10E'
15	'489905'	1896	11	.	.	20.3	3.98	.	3.92	'1896-97'	.	'50E'	.	'50E'	.	'10E'
16	'489905'	1896	12	.	.	20.8	4.44	.	0.46	'1896-97'	.	'50E'	.	'10E'	.	'10E'
17	'489905'	1897	1	.	.	1.12	5.56	.	1.12	'1896-97'	.	'10E'	.	'10E'	.	'10E'
18	'489905'	1897	2	.	.	1.95	6.39	.	0.83	'1896-97'	.	'10E'	.	'10E'	.	'10E'
19	'489905'	1897	3	.	.	3.03	7.47	.	1.08	'1896-97'	.	'10E'	.	'10E'	.	'10E'
20	'489905'	1897	4	.	.	4.24	8.68	.	1.21	'1896-97'	.	'10E'	.	'10E'	.	'10E'
21	'489905'	1897	5	.	.	5.79	10.23	.	1.55	'1896-97'	.	'10E'	.	'10E'	.	'10E'
22	'489905'	1897	6	.	.	8.13	12.57	.	2.34	'1896-97'	.	'10E'	.	'10E'	.	'10E'
23	'489905'	1897	7	.	.	9.24	13.68	.	1.11	'1896-97'	.	'10E'	.	'10E'	.	'10E'
24	'489905'	1897	8	.	.	9.81	14.25	.	0.57	'1896-97'	.	'10E'	.	'10E'	.	'10E'
25	'489905'	1897	9	.	.	10.1	14.56	.	0.31	'1896-97'	.	'10E'	.	'10E'	.	'10E'
26	'489905'	1897	10	.	.	11.8	1.72	.	1.72	'1897-98'	.	'10E'	.	'10E'	.	'10E'
27	'489905'	1897	11	.	.	14.8	4.7	.	2.98	'1897-98'	.	'10E'	.	'10E'	.	'10E'
28	'489905'	1897	12	.	.	15.6	5.5	.	0.8	'1897-98'	.	'10E'	.	'10E'	.	'10E'
29	'489905'	1898	1	.	.	0.31	5.81	.	0.31	'1897-98'	.	'10E'	.	'10E'	.	'10E'
30	'489905'	1898	2	.	.	1.52	7.02	.	1.21	'1897-98'	.	'10E'	.	'10E'	.	'10E'
31	'489905'	1898	3	.	.	2.92	8.42	.	1.4	'1897-98'	.	'10E'	.	'10E'	.	'10E'

Figure 4. Example data from the United States Historical Climatology Network

To obtain PRISM data, see instructions in section 3 of this SOP.

NCDC data can be obtained at http://www.ncdc.noaa.gov/oa/ncdc.html.

Be sure to carefully check NCDC data from these sources for outliers and physically unreasonably values. See Kittel et al. (2010) for more detail on screening climate data.

Data from the NCDC is formatted like the file “NCDC_example.csv" which is in Regionalization_Example_Data_Format.pdf available at the RMCP SharePoint site for Tools.

4.3 Format the data

Create separate data files for (A) summer [Jun – Aug] precipitation, (B) winter [Dec. – Feb] precipitation, (C) summer dew point temperature (D) winter dew point temperature, (E) summer temperature, and (F) winter temperature. See the file “PCA_winter_precip_data_file_example.csv” (in Regionalization_Example_Data_Format.pdf available at the RMCP site for Tools) for more information.

Make sure that the time period being analyzed is the same for all stations within each file. Eliminate months that have missing values for any weather stations.

Details:
Several python scripts are available at the RMCP SharePoint site for Tools to make this process easier as described below. All scripts were written for Python v. 2.6 running on Fedora Linux (v.10). If your original data files are not formatted exactly like the examples provided in USHCN_example.csv, you will need to edit these scripts before you use them. Carefully double-check the output of each script before proceeding to the next step. If necessary, edit the Python statements that control the data parsing.

If you are not familiar with Python, Excel macros will do the same thing. For a small number of stations, hand-editing the data files may be a reasonable alternative.

The Python scripts are as follows:

"RMCP Python NCDC First Pass Cleaner.py" --This makes the NCDC more tractable. Be sure you have screened and cleaned the data before you run this script. Run this separately on each station's data file. You may need to edit this script if NCDC changes the format of their data files or if you select different download options than those shown in the example files.

"RMCP Python ReportingUnits NCDC Data Parser.py" – This splits the output files from script (i) into the six seasonal temperature and precipitation files described above. When you finish using this script, you will have six files for each station.

"RMCP Python ReportingUnits USHCN Data Parser USHCN.py" – Same as ii but for USHCN data.

"RMCP Python ReportingUnits File Join.py" – Each station has missing values that occur for different months. Furthermore, the period of record varies slightly for each. This script automatically matches data by month (aligning rows, taking into account gaps and missing values) from two station files (the output files from scripts ii and iii) and joins them into a single file. After you have run this file one time, use its output for a second run to join a third file to the two stations that were just joined. Continue to run this script, joining new stations, until you have assembled a file with data from all of your weather stations.

"RMCP Python ReportingUnits Remove Months with Missing Values.py" – Run this script on the six output files from the filejoiner script. It ensures that the period of record is the same for all stations and that there are no missing values.

4.4 Perform the PCA

Suggested analysis scripts above are written in the R language (R Development Core Team 2009) and are available on the RMCP Sharepoint site for Tools.

Perform the analysis separately on all six of the data files produced by Step 4.3.

Be sure to run one section of the script at a time or some of your graphical results will be over-written. It is also important to evaluate the results of each step in the script before continuing. Overwriting may be avoided by ensuring the History Recording is on from the graphics window.

The script requires the R libraries "RSEIS" and "rgl." Comments in the script describe the purpose of each step.

As currently written, the script detrends, scales, and uses a natural-log transformation of the data. The scaling step is located in the PCA statement. Comrie and Glenn (1998) suggest trying a square root transformation as an alternative. Tercek et al. (in prep) suggest trying both transformations and comparing the PCA results. PCA is robust in the face of non-normality. The purpose of the transformation is not to normalize the data, but to standardize the magnitude of variance within each weather station's data.

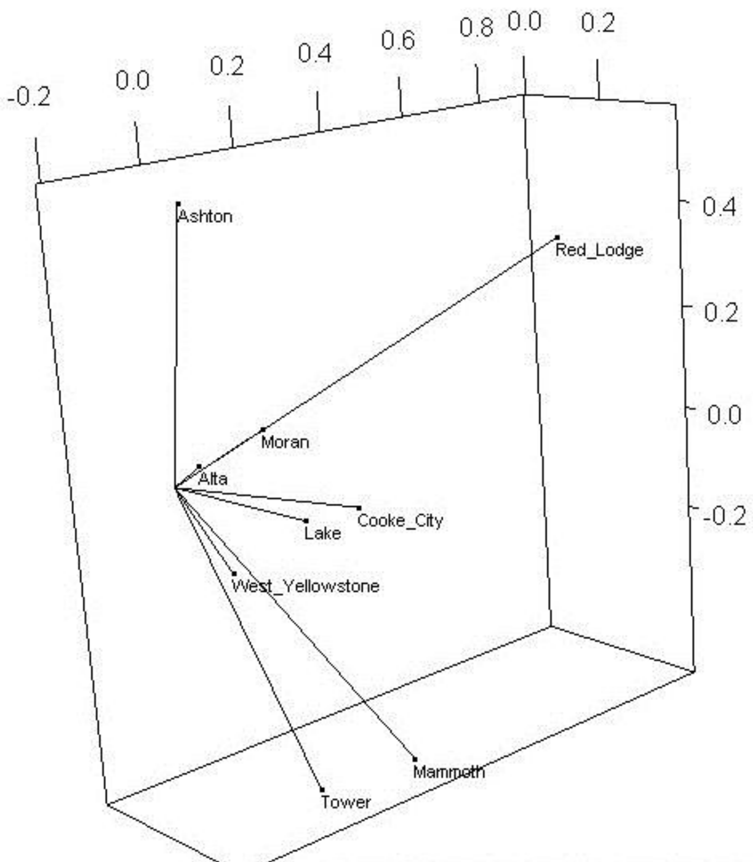
As currently written, the script uses oblique rotation of the PCs. Try varimax rotation and compare the results, as described in the R script. Preliminary analysis with GRYN data revealed no differences between oblique and varimax rotation.

4.5 Interpretation

Use scree plots (included in the R script) to help you determine how many principal components (PC's) to keep. How much of the variance is explained by each Principal Component?

The last section of the R script provides a few example methods for plotting your Principal Components against known explanatory variables such as station elevation, latitude, and longitude.

Compare the results of the principal components analysis to those from the cluster analysis. Do weather stations from different zones (as defined by the cluster analysis) plot separately in the principal components analysis? Figure 6 shows an example plot from this procedure. Use climograms and maps of weather station locations to interpret the different dynamics captured by the PCA vs. cluster analysis.



* Three components explain 81.6% of the variance.

Figure 5. Plot of Yellowstone and Grand Teton area weather stations against the first three principal components derived during a preliminary analysis of inter-annual winter precipitation patterns. This analysis agrees with the results of the cluster analysis (Protocol Narrative Fig. 2.1). Mammoth and Tower (northern range weather stations) plot separately and correspond to a zone defined by the cluster analysis. Lake and Cooke City agree with a second zone defined by the cluster analysis. The remaining stations within GRYN are in the third zone delineated by the cluster analysis. Red Lodge and Ashton, which are outside the GRYN area of interest, have been included to test the ability of the analysis to separate outlying areas.

5 - Snowpack Development and Melt Regime

Within climate zones distinguished by the two methods just described, sharp environmental contrasts may yet occur with elevation, where surface climates are similar but where snowpack stays on the landscape late into the spring. For these areas, the growing season does not begin until the snowpack is nearly gone. Snow cover timing can be used to estimate the stratification of the weather stations according to elevation.

For each weather station, 1971 – 2000 daily snow cover data can be downloaded from the NCDC and NRCS web sites (cited above). Since COOP and SNOTEL stations collect snow data incommensurately, with COOP stations reporting snow depth and SNOTEL reporting snow water equivalent (SWE), winter length is estimated as the number of days with snow cover greater than zero.

Station data files are organized according to water year, which runs from October 1st –September 30th of the following year, and analyzed by a script written in Scientific Python. The script determined the start and end dates of the winter season with the following rule set:

1. To correct for the fact that SNOTEL stations record SWE in tenths of inches, but COOP stations do not record a measurement until snow depth exceeds one inch, SNOTEL data are not considered greater than zero until they exceeded 0.5 inches SWE. All non-zero COOP snow depth values were counted as days with snow cover.

2. To correct for the fact that there are often several isolated snow events in early fall and late spring, winter is not deemed as "started" until the seventh day of snow cover is encountered in the water year. Similarly, winter is not over until the fourteenth consecutive snow free day is encountered.

3. In the COOP station files, data flagged with "2" (invalid data element), "T" (failed internal consistency check), and "U" (failed area consistency check) are replaced with missing values. If any month has more than seven missing values after this replacement, the entire water year is excluded from the analysis.

For each year at each weather station, the first day of winter, last day of winter and length of winter in days are estimated. Mean winter length is then calculated across years. Estimates from stations with fewer than six years of valid data are discarded. In order to assign elevation-based strata to the zones, groups of homogenous mean winter lengths are found with Ryan-Einot-Gabriel-Welsch posthoc tests.

If elevation-based sub-zones are needed, long-term average snow on/off dates could be used in a cluster analysis to distinguish areas dominated by early and/or late snowpack. Data sources for this analysis may include SNODAS's SWE or satellite-observed fractional snow cover, both from the National Operational Hydrologic Remote Sensing Center (NOHRSC).

6 - Literature Cited

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Rocky Mountain Climate Protocol SOP Quality Control

Greater Yellowstone & Rocky Mountain Networks: March 2011 version

1 - Change History

Revision History Log

Previous Version #	**Revision date**	**Author**	**Changes made**	**Section and paragraph**	**Reason for change**	**New Version #**
1	20101216	Ashton	Minor formatting, removed sections with no content			2010
2010	March 4, 2011	Rob Daley – GRYN, with input from others at GRYN, ROMN, SIEN	Updated citations	Throughout	Scheduled Review	March 2011

2 - Data Quality Control for Status and Trend Reporting

Data quality control requirements and activities for annual reports are limited in scope pending the more comprehensive and time-consuming expert review required for data used in Climate Variability and Trend reports. Data reported annually are reviewed briefly for obvious errors and problems according to the standards provided in Table 4 and Figure 3 from Kittel and others (2010). To prepare data for semi-annual variability and trend reporting a climatologist is required to perform the substantial quality control activities described in Kittel and others (2010) and further described in *SOP Trend Analysis and Reporting*.

Table 1. Quality control for *Annual* status reports

Input	Event Structure	Temporal or Spatial	Data Errors, Biases, Outliers, and Multiday Observations	Inhomogeneities		Completeness		Network Dataset Product
				Known	Unknown	Daily Data	Monthly Data	
COOP	Daily	Temporal	As for monthly COOP dataset, *except*: Multiday observations omitted	As for COOP seasonal	As for COOP seasonal	Missing values *not* infilled	*N/A*	Daily dataset (*Provisional*)
	Seasonal Inter-annual variability	Spatial Temporal	Numerical & visual checks Consult forms and observer Manual removal Multiday obs crossing month boundary parsed (e.g., ppt) or omitted	Accept source QC Known but not corrected by source - only correct if easily done If not, document for next *Trends* report	Accept source QC Attach caveats to results	Missing values – remove month if value > threshold: - missing T >5d - missing ppt >3d - other vars: 15% missing	Accept source QC, document missing months Attach caveats to results	Monthly-Seasonal-Annual Dataset (*Provisional*)
SNOTEL	Seasonal Inter-annual variability	Spatial Temporal	Numerical & visual checks Manual removal	*As for COOP*	*As for COOP*	Accept source QC	*N/A*	*Provisional*
Streamflow	Daily Seasonal Inter-annual variability	Spatial Temporal	Numerical & visual checks Manual removal	*As for COOP*	*As for COOP*	Accept source QC	*N/A*	Unregulated Stations *(Provisional)*
PRISM	Seasonal	*N/A*	Accept source QC	Accept source QC	Accept source QC	*N/A*	Accept source QC	Monthly-Seasonal-Annual Dataset (*Provisional*)
SNODAS	Seasonal	*N/A*	Accept source QC	Accept source QC	Accept source QC	Accept source QC	*N/A*	Monthly-Seasonal-Annual Dataset (*Provisional*)

Table 2. Quality control for variability and *Trends* report, temporally representative stations only

<table>
<tr><th rowspan="2">Input</th><th rowspan="2">Event Structure</th><th rowspan="2">Data Errors, Biases, Outliers, and Multiday Obs</th><th colspan="2">Inhomogeneities</th><th colspan="2">Completeness</th><th rowspan="2">Network Dataset Product</th></tr>
<tr><th>Known</th><th>Unknown</th><th>Daily Data</th><th>Monthly Data</th></tr>
<tr><td rowspan="2">COOP</td><td>Daily</td><td>Apply high-quality QC (Figure 2)
Numerical & visual checks
Consult forms and observer
Manual removal
Multiday observations omitted</td><td>Apply high-quality QC (Figure 2)</td><td>Apply high-quality QC (Figure 2)</td><td>Missing values not infilled</td><td>N/A</td><td>Daily dataset
(Final)</td></tr>
<tr><td>Inter-annual variability</td><td>As for Daily COOP, except:
Multiday observations parsed (ppt) or omitted, then infilled</td><td>Apply high-quality QC (Figure 2)</td><td>Apply high-quality QC (Figure 2)</td><td>Apply high-quality QC (Figure 2)
Missing values infilled</td><td>If only monthlies available – Accept source QC, document missing months
Attach caveats to results</td><td>Monthly-Seasonal-Annual Dataset
(Final)</td></tr>
<tr><td>SNOTEL</td><td>Inter-annual variability</td><td>Numerical & visual checks
Manual removal</td><td>As for COOP</td><td>As for COOP</td><td>Accept source QC</td><td>N/A</td><td>Final</td></tr>
<tr><td rowspan="2">Streamflow</td><td>Daily</td><td rowspan="2">Apply high-quality QC (Figure 2)
Numerical & visual checks
Manual removal
Multiday observations omitted
Check data gone from provisional to official
Consult observer</td><td rowspan="2">Apply high-quality QC (Figure 2)</td><td rowspan="2">Apply high-quality QC (Figure 2)</td><td rowspan="2">Missing values not infilled</td><td rowspan="2">N/A</td><td>Daily dataset
(Final)</td></tr>
<tr><td>Inter-annual variability</td><td>Monthly dataset
(Final)</td></tr>
</table>

Table 3. Quality control for decadal region shifts, long term trends, and teleconnects, the latter two of which are treated in the same manner concerning inter-annual variability.

All datasets	Decadal Regime Shift	Regime-shift subset of Monthly-Seasonal-Annual Dataset (*Final*)	Correct only with great care – will affect shift detection	Ignore possibility of artificial inhomogeneities not supported by stationn histories or other data. Attach caveats to results	As for inter-annual variability	As for inter-annual variability	As for inter-annual variability
Long-term trends	As for inter-annual variability	As for inter-annual variability	As for inter-annual variability	As for inter-annual variability	As for inter-annual variability	As for inter-annual variability	As for inter-annual variability
Indices	*N/A*	As for inter-annual variability	As for inter-annual variability	As for inter-annual variability	As for inter-annual variability	As for inter-annual variability	As for inter-annual variability

Table 4. Quality control for regional analyses to derive reporting units

Input	Event Structure	Data Errors, Biases, Outliers, and Multiday Observations	Inhomogeneities		Completeness		Network Dataset Products
			Known	Unknown	Daily Data	Monthly Data	
PRISM	Temporal patterns	Accept source QC	Accept source QC	Accept source QC	*N/A*	Accept source QC	Monthly-Seasonal-Annual Dataset (*final*)
SNODAS		Accept source QC			Accept source QC	*N/A*	
Station Data		**Apply high-quality QC (Figure 2)** Numerical & visual checks Consult forms and observer Manual removal Multiday obs parsed(ppt) or omitted then infilled	**Apply high-quality QC (Figure 2)**	**Apply high-quality QC (Figure 2)**	**Apply high-quality QC (Figure 2)** Missing valued infilled	If only monthlies available – accept source QC, document missing months Attach caveats to results	

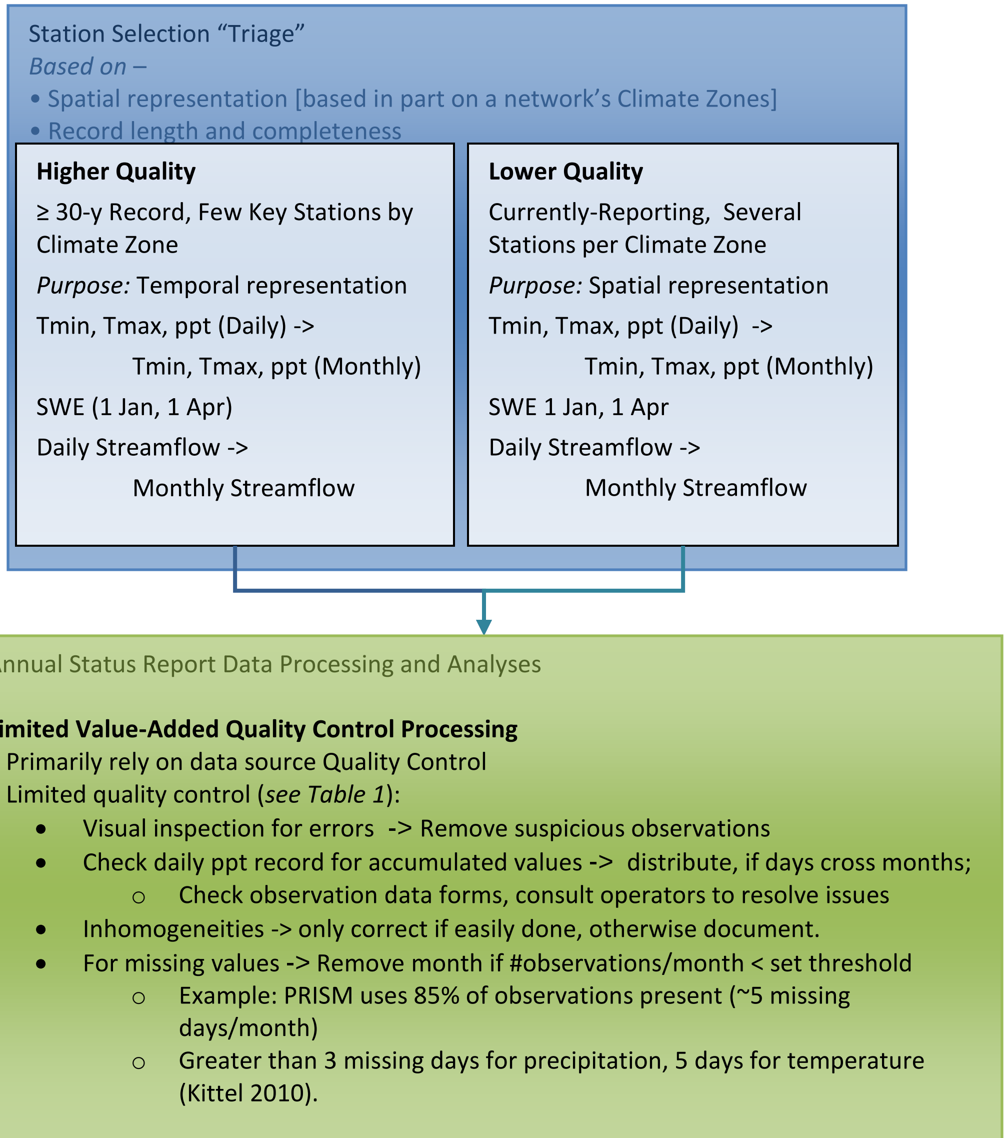

Figure 1. Process framework for annual climate status report using limited-value quality control. Refer to Kittel (2010) for supporting details.

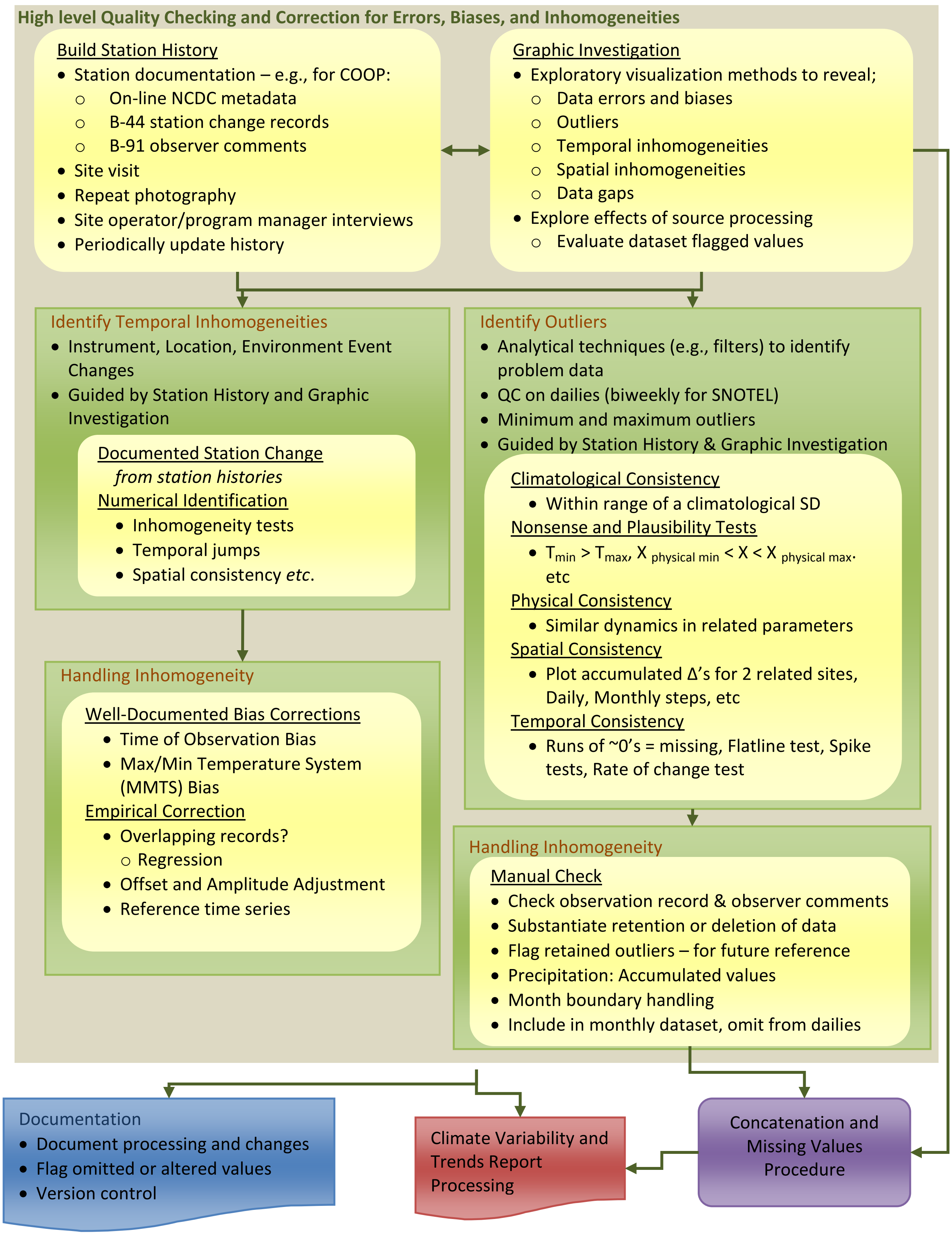
High level Quality Checking and Correction for Errors, Biases, and Inhomogeneities
Build Station History
Station documentation – e.g., for COOP:
On-line NCDC metadata
B-44 station change records
B-91 observer comments
Site visit
Repeat photography
Site operator/program manager interviews
Periodically update history
Graphic Investigation
Exploratory visualization methods to reveal;
Data errors and biases
Outliers
Temporal inhomogeneities
Spatial inhomogeneities
Data gaps
Explore effects of source processing
Evaluate dataset flagged values
Identify Temporal Inhomogeneities
Instrument, Location, Environment Event Changes
Guided by Station History and Graphic Investigation
Documented Station Change
from station histories
Numerical Identification
Inhomogeneity tests
Temporal jumps
Spatial consistency etc.
Identify Outliers
Analytical techniques (e.g., filters) to identify problem data
QC on dailies (biweekly for SNOTEL)
Minimum and maximum outliers
Guided by Station History & Graphic Investigation
Climatological Consistency
Within range of a climatological SD
Nonsense and Plausibility Tests
$T_{min} > T_{max}$, $X_{physical\ min} < X < X_{physical\ max}$, etc
Physical Consistency
Similar dynamics in related parameters
Spatial Consistency
Plot accumulated Δ's for 2 related sites, Daily, Monthly steps, etc
Temporal Consistency
Runs of ~0's = missing, Flatline test, Spike tests, Rate of change test
Handling Inhomogeneity
Well-Documented Bias Corrections
Time of Observation Bias
Max/Min Temperature System (MMTS) Bias
Empirical Correction
Overlapping records?
Regression
Offset and Amplitude Adjustment
Reference time series
Handling Inhomogeneity
Manual Check
Check observation record & observer comments
Substantiate retention or deletion of data
Flag retained outliers – for future reference
Precipitation: Accumulated values
Month boundary handling
Include in monthly dataset, omit from dailies
Documentation
Document processing and changes
Flag omitted or altered values
Version control
Climate Variability and Trends Report Processing
Concatenation and Missing Values Procedure

Figure 2 (preceding page). Processing framework for high-level quality control of the climate datasets. Refer to Kittel and others (2010) for supporting details.

3 - References

Kittel, T., S. Ostermann-Kelm, B. Frakes, M. Tercek, S. Gray, and C. Daly. 2010. A Framework for Climate Analysis and Reporting for Greater Yellowstone (GRYN) and Rocky Mountain (ROMN) networks: A report from the GRYN/ROMN climate data analysis workshop, Bozeman, Montana, 7–8 April 2009. Final report (Feb. 18, 2010) prepared for the National Park Service, Greater Yellowstone Inventory and Monitoring Program, Bozeman, Montana, USA. 54 p.

Rocky Mountain Climate Protocol SOP Station Selection

Greater Yellowstone & Rocky Mountain Networks: March 2011 version

1 - Change History

Revision History Log

Previous Version #	**Revision date**	**Author**	**Changes made**	**Section and paragraph**	**Reason for change**	**New Version #**
1.0	20101216	Ashton	Minor formatting			2010
2010	March 4, 2011	Rob Daley – GRYN, with input from others at GRYN, ROMN, SIEN	Adjustments for clarity.	Various	Scheduled Review	March 2011

2 - Introduction

Station selection is based on two objectives (Kittel et al. 2010):

Provide an extensive *spatial* picture of climate across the network domain, its constituent climate zones, and the region or regions that include network parks. This is a key part of describing the year in review in the climate status reports.

Provide for a rigorous *temporal* analysis of interannual variability, regime shifts, and long term trends in key daily, monthly, seasonal, and annual variables. This is for both the status and trends report.

Although specific criteria determine which stations to use, it may be necessary to relax or adjust criteria in order to achieve adequate station coverage for a region. The station selection process is not complete without expert review; this process cannot be shortcut by using just an objective approach (Kittel et al. 2010).

3 - General Approach to Station Selection

Selection is a 'triage' process, resulting in stations for temporal analyses, spatial analyses, and, lastly, auxiliary stations (Kittel et al. 2010). Below are general considerations for station selection and categorization. A single station may fall into the spatial only analysis group, the spatial and temporal analysis groups, or the auxiliary group.

Temporal analysis stations. The strictest selection criteria identify daily and monthly stations suitable for temporal analyses. These criteria are largely based on Gray (2008). Stations in this analysis group meet the following requirements:

- A continuous record having gaps no more than 1 year (per Gray 2008).

- A record at least 25-40 years depending on the variable and timestep; at least 50 years are needed for regime shift analysis. The longer period for regime shift analyses is to limit analyses to records most likely to capture multidecadal shifts. However, 50 years is an arbitrary cutoff and can be relaxed. When selecting stations to represent a given climate zone, stations with longer records will be given preference over others. For monthly temperature and precipitation (COOP), records will ideally cover the 1971-2000 period, the most recent period for calculating '30-year climate normals'. This period is the baseline for statistical comparisons.

- Relatively high quality – that is, records with manageable data issues (biases, errors, inhomogeneities, missing values). See Gray (2008 Data Issues Report, p. 1-7) for specifics.

- Providing representation for a climate zone – other criteria may be relaxed if needed to get at least one good station to represent a zone. Stations with problematic records but in critical locations will warrant a high level of effort to create a 'clean' data series.

- Finally, as the "best of the best," stations will be narrowed down to a few key stations per zone for temporal analysis. This is to make quality control and correction tasks manageable during the 5-year Trends Report cycle.

Spatial analysis stations. Stations for spatial analyses include these 'temporal analysis stations' *plus* additional stations that:

- Are currently reporting monthly parameter values or provide data to compute monthly values (i.e., dailies not required).

- Contribute significantly to spatial coverage within each climate zones – that is, are not redundant in their information about the year for a particular climate zone.

- Have sufficient quality during the previous calendar and water-years, requiring minimal quality correction or whose problems are judged by a climatologist as acceptable for the purpose of spatial analyses.

Remaining auxiliary stations. Remaining available stations are not used directly in temporal or spatial analyses, but may yet have value during the infilling process if they span gaps in the otherwise higher quality stations.

Selection changes

Periodic review (e.g., in years of trend reporting) of stations assigned to each category is necessary to account for stations are dropped from and added to climate monitoring networks. While preparing the first status report and the historical database, station selection may be refined to address insurmountable data problems.

4 - Station Selection Guidelines by Provider

4.1 Specific selection criteria

The specific selection criteria provided here from Gray (2008) identify a network of stations that provide good spatial coverage within each park or climate zone and screen these representative stations to produce a set of stations with the highest quality data. Limiting the number of stations eases the workload involved to acquire, process, review, analyze, and report on station data. The intent is not to overburden report writers with an unmanageable number of stations, while maintaining a high-quality, representative data set for reporting.

4.2 Station selection criteria for NWS-COOP Stations

4.2.1 Representation of Intraregional Variability

First consider stations that span the variability within each of the climate zones identified for reporting purposes (see SOP Defining Climate Zones) by mapping all COOP stations and listing each station's history and elevation.

4.2.2 Data Quality and Availability

Review the length, quality and completeness of potential station records.

1. Keep only those stations with > 40 years of continuous record (i.e. no gaps > 1 year)
2. Keep only those stations that have operated continuously between 1971 and 2000. (Criteria 1 and 2 reflect the need to calculate 30-year averages or so-called "climatic normals" for these stations.
3. Station records must include daily min/max temperature and precipitation.
4. Station records must not contain more than 5% missing data since January 1, 1990.
5. Stations may not have known siting issues or recurring instrumentation problems
6. Stations must provide year-round observations.

Easy access to station data is a key concern in the site selection process. This generally comprises stations with data available in the Applied Climate Information System (http://www.rcc-acis.org/) or accessed freely via the Western Regional Climate Center (http://www.wrcc.dri.edu/) or the state climate offices (http://www.stateclimate. org/).

4.2.3 Expert Input
While objective criteria such data completeness and length-of-record provide the basis for an initial screening of candidate stations, expert input plays a critical role in the final selections. Experts should be consulted to review potential stations based on the following criteria:

1. Siting. Based on site visits, plus local knowledge and/or photographs, the location of each station should be reviewed to determine if the station is reasonably well-sited (e.g. away from heat sources) and maintained.

2. Station history. Station histories from National Climatic Data Center (http://mi3.ncdc.noaa.gov/) and "Cooperative Network Station Reports (B-44)" should be reviewed for station moves and potential siting and/or equipment problems. Expert knowledge of station histories could also be considered.

3. Representation of intra-regional variability. Expert input on the distribution of stations and their ability to capture sub-regional variability should also be considered.

Gray (2008a) found that all of the candidate sites for GRYN had moved multiple times, but this is often the case with all types of long-term climate stations. The station at Mammoth YNP, for example, has moved six times since 1948, but the error introduced in this case can be corrected or ignored because the >100 years of data from this station is more important than a few intermittent station location adjustments.

4.3 Station selection criteria for SNOTEL stations
SNOTEL sites have the distinct advantage of hourly readings and telemetry and provide the best means for tracking the development and melting of the snowpack. The specific criteria used in SNOTEL selection are listed below. Snowcourse stations may be used in the temporal and/or spatial analysis station groups when necessary to improve representation.

4.3.1 Representation of Intra-regional Variability
The review process for potential SNOTEL sites is similar to that for NWS-COOP stations. A goal is to include SNOTEL sites in each of the major drainages within a region. SNOTEL and snowcourse station locations should be mapped along with climate zone boundaries to allow evaluation of representativeness.

4.3.2 Data Quality and Availability
Stations with > 25 years of continuous record are the initial target. Automated measurements plus telemetry and rigorous site maintenance by NRCS for SNOTEL stations mean there are very few missing data points at any of the sites. Snowcourse stations may have longer histories that are more prone to have data gaps.

Data are readily available from NRCS. Because data from Snowcourse stations are manually collected, these stations generally have longer histories and are more prone to data gaps.

4.3.3 Expert Input
The expert input process for SNOTEL and snowcourse stations should be used where necessary to confirm decisions regarding representativeness of a station, and/or when to relax criteria to gain adequate station coverage.

4.4 Station selection criteria for USGS gage stations

4.4.1 Representation of Intra-regional Variability
Include gages on each of the major drainages within a region. Map the location of each gage station to facilitate the selection process.

4.4.2 Data Quality and Availability
Gages with > 30 years of continuous record is an appropriate target. Generally speaking, data completeness is far less of an issue with Streamgages than with NWS-COOP stations. USGS estimates missing data using a robust, well-documented procedure, and automated and telemetered gages reduce the chances for missing data.

To the extent possible, limit consideration of gaging stations to those that are automated with telemetry and stations that are archived in the USGS' National Water Information System (NWIS). All station records in the NWIS are freely available to the public.

4.4.3 Regulated vs. Non-regulated Flows
One additional concern for Streamgage selection is the ability to capture the natural hydroclimatic variability represented in unregulated flows (i.e. no dams, diversions or major depletions upstream), as well as the impacts of regulated flows (i.e. dam controlled) on park units. As such, final gage selection is designed to include measures of unregulated flows in all major drainage basins, plus regulated inflows/outflows that affect parks.

4.4.4 Expert Input
Spatial coverage and the ability to balance intraregional variability against numbers of sites is an important consideration. An example of where expert opinion was particularly helpful in selecting a single gage station was in the Snake River drainage in GTNP below Jackson Lake Dam (Gray 2008a). Two gage records are available from this stretch of river, namely the Snake River near Moran, WY and the Snake River at Moose, WY. The Moran gage offers nearly continuous records going back to 1904, whereas the Moose record goes to 1995. In the end, Gray (2008a) chose the Moose gage because it captures both outflows from Jackson Lake Dam and inputs from major tributaries like Pacific Creek and the Buffalo Fork River. In other words, the gage at Moose was thought to be more representative of basin-scale variability than the longer gage record from Moran.

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Rocky Mountain Climate Protocol SOP Optional Park Index

Greater Yellowstone & Rocky Mountain Networks: 2010 version

1 - Change History

Revision History Log

Previous Version #	Revision date	Author	Changes made	Section and paragraph	Reason for change	New Version #
1.0	20101216	Ashton	Minor formatting			2010

2 - Introduction

There are three indices that can be calculated that for a park.

- Mean daily temperature (TMEAN)
- Precipitation (PPT)
- Snow Water Equivalent (SWE)

These basic measures are modified by following elements.

3 - Creating the Index

1.1. Data Quality Evaluation

1.2. Distance From Park as a Weighting Factor

How far a station is from the park is used to change the importance of its component part in the index. The equation to figure the distance weighting factor for a station for a day follows:

d = Distance of station from the park.
bd = Basic distance weighting for the station

$$bd = 1/d^2$$

Dist = the sum of the bd's for all of the stations reporting for a day

dw = daily weight for a station

$$dw = bd / Dist$$

This (dw) is a percentage value for a station's measure for a day. If only one station reports its full measure is used no matter how far it is from the park. If several report then each measure becomes a percent of the final index.

[i.e. For Park A if station C is 2 km distant and reports a temp of 55 degrees farenheight and D is 3 km and reports 60 degrees farenheight (both are at about the same elevation and no other station is reporting) the index calculation for TMEAN is:

1/2^2 = 1/4 = .25
1/3^2 = 1/9 = .11
Total dw = .25 + .11 = .36, (.25/.36 = .694), and (.11/.36 = .306).
Therefore, TMEAN = (55 * .694) + (60 * .306) = 56.53]

1.3. Elevation Corrections

Temperature

Boyles gas law describes the relationship between pressure, volume, and temperature. As elevation increases, air pressure goes decreases and temperatures consequently decreases at 3.56 °F (1.98 °C) per 1000 ft, or the dry adiabatic lapse rate. Conversely, a decrease in elevation causes temperatures to increase at the same lapse rate. This is know as the Dry Adiabatic Lapse Rate (DALR). It refers to a laboratory constant for temperature change in a volume of dry air (no condensation) as a result of altitude change – Boyle's Law. Since the atmosphere is dynamic what is actually seen in the troposphere varies. However, while the Environmental Lapse Rate should be the same as the DALR, certain factors may distort this. First, saturated air will cool more slowly as water condenses and releases energy via a change in state (also known as the Saturated Adiabatic Lapse Rate). Second, areas that frequently have air inversions observe increasing temperatures with height within the lower levels of the atmosphere. In measuring the Environmental Lapse Rate observed at each park any significant variation from the DALR must be explained.

Park	Summer (JJA) Lapse Rate (degree F /feet)	Summer R2	Winter (DJF) Lapse Rate (degree F /feet)	Winter R2

GRKO	-4.3 /1000	.2673	0.3 /1000	.0014

Table 1. Environmental Lapse Rates for Winter and Summer

This process in the ROMO prototype index project last year showed this to be true for that park. The GRKO prototype project situation is different. The change in temperature proved true for summer months but not for winter months (perhaps a temperature inversion). Therefore a correction factor was added to a station's measure based on its elevation difference only for the summer months (April – September). For GRKO in summer the slope of the regression was -0.0043 with an R^2 of .2673.

Precipitation

Park	Summer (JJA) Precipitation Coefficient (inches/foot)	Summer R2	Winter (DJF) Precipitation Coefficient (inches/foot')	Winter R2
GRKO	0.000005	.0205		

Table 2. Precipitation Coefficients for Winter and Summer

The elevation also has an impact on precipitation. In GRKO a preliminary regression showed this to have a slope of .000005 per foot with an R^2 of .0205, not very significant. However, the change was factored in so that future park projects would have the calculation already in place.

def = (Difference in station elevation from GRKO Elevation / 1000)

e = elevation correction = (3 * def) for TMEAN

e = elevation correction = (0.000005 * def) for PPT

Calculating a SWE index specific to the park is generally not appropriate unless much of the park is at high elevations. Calculating SWE for a watershed scale is appropriate in other cases.

1.4. Determining Daily Value

TMEAN or PPT have the same over all equation:
C = Daily index

S = Station Daily Measure

e = is the correction for elevation

dw = is the weighting percentage for a station for a day based on distance from the park

$$C = \sum (S + e)dw$$

The overall indices and 30 year indices are the averages of all of the daily indices (C) for all of the days in a month for all of the relevant years. The Water Year indices are the averages for all of the days in each month of the twelve months in a water year (October through September).

Rocky Mountain Climate Protocol SOP Status Reports

Greater Yellowstone & Rocky Mountain Networks: 2010 version

1 - Change History

Revision History Log

Previous Version #	**Revision date**	**Author**	**Changes made**	**Section and paragraph**	**Reason for change**	**New Version #**
1.0	20101216	Ashton	Minor formatting			2010
2010	March 4, 2011	Rob Daley – GRYN, with input from others at GRYN, ROMN, SIEN	Adjusted numerous sections for clarity and to address lessons learned from prior year reporting.	Various	Scheduled Review	March 2011

2 - Introduction

This SOP provides a climate status report framework intended to summarize and interpret temperature, precipitation and drought metrics within and around a park unit for 1-3 calendar years, and snowpack, snow water equivalent, and streamflow for 1-3 water years (October – September). The schedule to complete status reports annually versus semi-annually can vary by park and I&M network based on local requirements. The primary audiences for routine status report are park staff and managers, researchers, and collaborators.

Station Data (points) and Raster Data (cell-based or grid)

Climate status reports summarize real data from specific locations (weather stations) as well as interpolated data for park landscapes, climate zones, and larger regions. Data from carefully scrutinized and selected stations provide a good foundation for understanding climate status and trend in and around parks. However, it is important for status reports to disclose and discuss limitations and exceptions to the reported information, including the following factors that directly affect station data and any derived, generalized, or interpolated values for landscapes between and around stations.

- Micro-scale climate – differences resulting from proximity to water, trees, vents, parking lots, walls, etc. that may affect representative measurements;
- Meso-scale climate – the location of the station relative to individual storm events, especially in summer when convective storms unevenly distribute rain;
- Data Errors – errors related to the instrumentation or recording of the information;
- Shortness and discontinuity of records – some stations do not have 30 years' worth of observations and/or have substantial data gaps.

To produce robust and continuous climate records and to address some of the factors affecting station data, existing raster data products are processed and reported for daily maximum and minimum temperature and total daily precipitation (PRISM - Daly et al. 2008) and snowpack (SNODAS). Status reports should state that while these raster datasets provide useful indicators of climate conditions within a park, they are not representative of any single point within a park and may not correctly represent climate signals relevant to certain ecological processes.

Baselines for comparison

When possible, use mean values from the established 30-year normal period (i.e., 1971-2000 as of 2009) for comparison to the current year's climate. In cases where data for the 30-year normal period are not available, use alternative comparisons such as the mean from the period of record or a recent 10-year period. Data may be reported in the form of percentiles, which are often appropriate because climate data are not always normally distributed, are skewed by outliers, and can be on different scales. Percentiles are used for all intra-annual departures because averages and normal ranges of a parameter change for each month. Likewise, percentiles are an effective way to normalize spatially distributed variations.

3 - Procedures

Status Report Timing and Overview

Due to the time it takes for providers to review, quality-control, and distribute the various data products used in status reporting, plan to initiate reporting approximately 6 months after the end of the water year (approximately the following April). The overview production steps listed here are explained in detail below:

1. Download the current NPS Natural Resource Technical Report Series template and save as a document for the park(s) and reporting period;
2. Follow the Data Acquisition SOP and work with the network data manager to obtain data that has undergone required quality control;
3. Analyze the current water and calendar year data and produce graphics using tools available in the RMCP Web site toolbox;
4. Insert graphics, tables, summary statistics and data into the template;
5. Consult with a climatologist as necessary and add text to interpret the current year climate data and graphics (methods and introduction will likely remain the same each year);
6. Obtain peer review on the draft report;

7. Edit report and submit to WASO.

Status Report Template

The annual reports should be published in the Natural Resource Technical Report Series (NRTR)**. The directions and details for submission can be found at** http://www.nature.nps.gov/publications/NRPM/**.**

The report should be titled: “Climate Status Report for <Park Unit(s)>, <Year(s)>”. A brief description of the report content is provided below:

Executive Summary: A brief (~300 words) abstract of the annual report highlighting where and if the year departs from normal/recent conditions. It should be concise and written for a broad audience including superintendents and the public.

Introduction: State the purpose and goals of the report, the definition of the water year, and basic information regarding the park of interest. In parks where multiple regions or zones are used for reporting, these should be described (e.g. west and east side of the continental divide).

Data and Methods: This should describe and provide web links to the original data sources, including the version identifier for compiled data used from the NPS Enterprise Climate Database, and/or direct from SNOTEL, COOP, and other providers. Describe the quality control measures taken as well as the calculation of any indices (e.g. standard precipitation index) or statistical tests used. Details may also be placed in an appendix.

Results and Discussion: Presenting each parameter of interest (e.g. temperature, precipitation, snowpack, drought and streamflow) in separate sections is straightforward and easy to interpret, with the narrative integrating across variables placed in a separate section or the summary. PRISM and SNOWDAS data should be presented for the region encompassing the park-unit. For each parameter, intra-annual and annual variation is discussed.

Conclusion:
The conclusion briefly and comprehensively synthesizes the results and discussion, and provides integration across climate variables. It should contain more detailed information than the Executive Summary.

Data Analysis and Graphics

For climate status reports, use English (°F and inches) and metric units (°C and mm) and include the components described below.

Overview of Data

1. Map and provide metadata for both the temporal analysis stations (those having long-term records) and spatial analysis stations (i.e., all stations within the domain reporting for the year(s) of interest) used in report. Report data completeness for each station (e.g. Garman

2008) and provide summaries of station documentation or site visits completed, along with reports on any maintenance issues identified during site visits.

2. Describe the data flow from original providers to NPS systems, along with data processing performed to prepare the data for summary reporting. Clearly explain how park staff can directly obtain or request the data used in the report.

Temperature

3. Overview for each park or climate zone.
    a. Use the Climate Grid Analysis Tools (see Sherrill and Frakes 2010, NRInfo RefCode = 2166778) to produce a timeseries from the PRISM data source to create monthly and annual anomaly histograms for recent 10+ years compared to the 30-year normals. See example anomaly histogram in Ashton et al. 2009 that was created using the park-index calculations and R code.
    b. Monthly Tmin and Tmax PRISM maps for each zone or region. Consider using one map per month/variable of the larger region along with park and climate zone boundaries.
4. Station specific data for each park or climate zone.
    a. Tables of average minimum and maximum daily temperatures and departures from 30–year normals per month for each of the selected COOP stations if available (for example, see Gray et al. 2010).
    b. For temporal analysis of COOP stations, plot year by month along with 30-year normals, or as deviations from normals. OPTIONAL: if necessary to provide adequate spatial coverage, also do this for spatial analysis COOP stations, but without baseline comparison.
5. Annual Timing Variables.
    a. Narrative discussing temperature during the past year, including discussion of annual timing and integrative variables: mean temperature, accumulated growing degree days, and diurnal temperature range, number of days with Tmin $\geq 90^{th}$ percentile (e.g., see Figure 1).
    b. Table with first and last freeze and frost dates, number of days below 0ºF and 32ºF or above 80ºF and 90ºF for COOP stations within the region (for example, see Table 3 in Gray et al. 2010).
    c. OPTIONAL: Graphs of other derived variables (as recommended by Kittel 2009). These optional pieces of the status report can be added gradually over time, or developed in the first trends report and then updated annually.

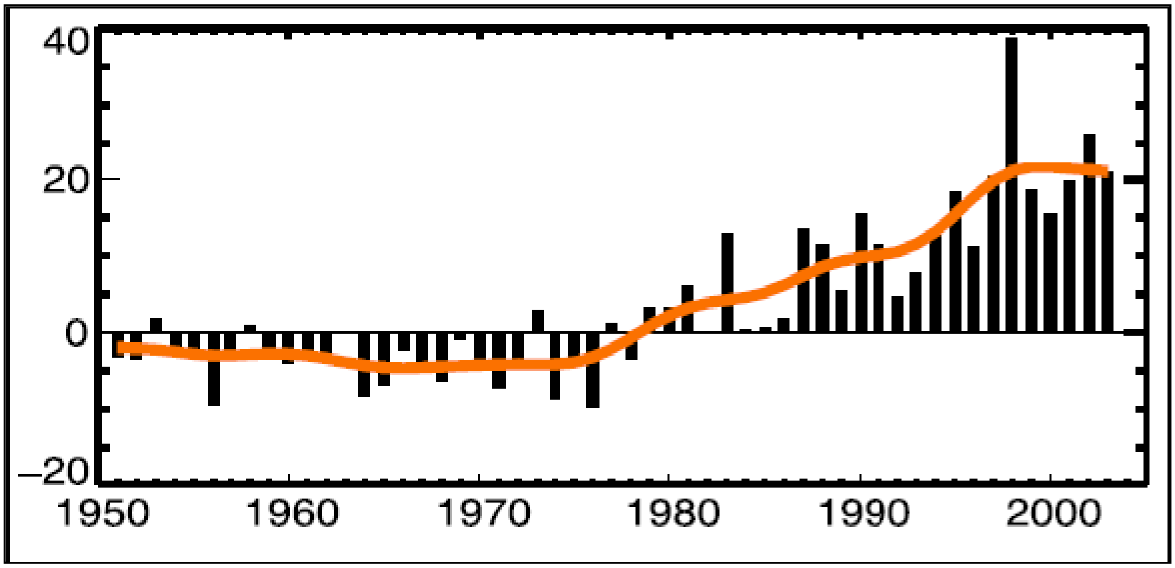

Figure 1 Historical change in temperature event frequency. This graph shows the number of days per year with Tmin >90th percentile. Image taken from Kittel (2009), modified from Trenberth et al. 2000 and Alexander et al. 2006.

6. OPTIONAL: Daily event structure.

   a. Evaluate daily event structure with frequency distribution plots. As described by Kittel (2009), the analysis of daily records can reveal the characteristic structure of weather events and the frequency of extreme events (see figure 2).

   b. Plot year by day (one box plot per month) for Tmin and Tmax (e.g., Garman 2008) for COOP stations. These box plots will be placed on the RMCP Web site and will not appear in the printed report.

   c. OPTIONAL: Plot the frequency distribution Tmin/Tmax as in Figure 2.

7. OPTIONAL: Interannual variability – provisional analysis.

   a. Trend analysis on Tmin and Tmax for one or more United States Historical Climatology Network (USHCN) stations per zone. The purpose of this analysis is to examine interannual variability in temperature, and provide context for the report between trends reports. See Kittel (2009) for trend analysis methods that include detrending data to test for serial correlation and using non-parametric Mann-Kendall test.

   b. Append current year's value to long term plots by year from Trends Report, without updating smoothing function. Be sure to include appropriate caveats.

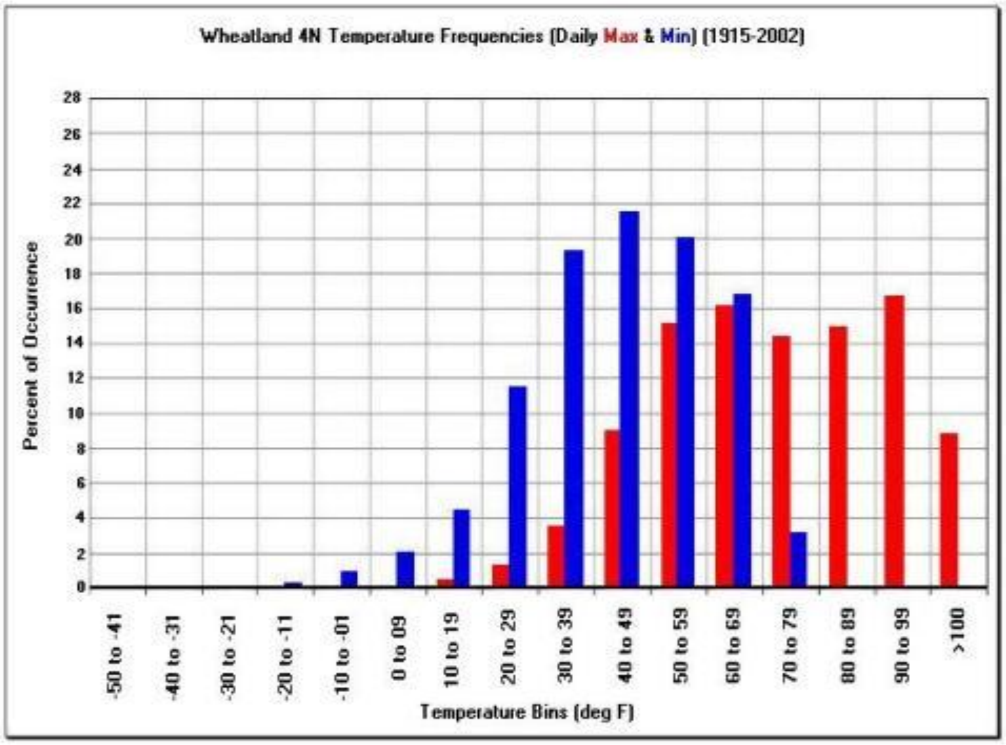

Figure 2. Taken from Kittel (2009). Example frequency distribution of Tmin and Tmax. Original image from Wyoming Climate Atlas, http://www.wrds.uwyo.edu/wrds/wsc/climateatlas/toc.html, 14 Mar 2007 update.

Precipitation

1. Overview for each park or climate zone.
   a. Use the Climate Grid Analysis Tools (see Sherrill and Frakes 2010, NRInfo RefCode = 2166778) to produce a timeseries from the PRISM data source to create monthly and annual anomaly histograms for recent 10+ years compared to the 30-year normals. See example anomaly histogram in Ashton et al. 2009 that was created using the park-index calculations and R code.
   b. Monthly total precipitation PRISM maps for each climate zone or region. Consider using one map per month showing the region and zone boundaries.
2. Station specific data for each park or climate zone.
   a. Tables of total precipitation and departures from 30–year normals per month for each of the selected COOP stations if available (for example, see Gray et al. 2010).
   b. For temporal analysis COOP stations, plot year by month along with 30-year normals, or as deviations from normals. OPTIONAL: if necessary to provide adequate spatial coverage, also do this for spatial analysis COOP stations, but without baseline comparison.
3. Annual Timing Variables.

a. Table or narrative including annual timing and integrative variables: number of days with precipitation, intervals between precipitation events, frequency of precipitation events that exceed a threshold.

b. OPTIONAL: Graphs of other derived variables. These optional pieces of the status report can be added gradually over time, or developed in the first Trends Report and then updated annually.

4. Daily event structure.

   a. Plot year by day (one box plot per month) for total precipitation (e.g., Garman 2008) for COOP stations. These box plots may or may not appear in the printed report.

   b. OPTIONAL: Frequency distribution graphics (e.g., see Kittel et al. 2010).

5. Interannual variability – provisional analysis.

   a. OPTIONAL: Trend analysis on total precipitation for one or more USHCN stations per zone. The purpose of this analysis is to examine interannual variability in precipitation, and provide context for the report between Variability and Trends Reports. See Kittel et al. (2010) for trend analysis methods that include detrending data to test for serial correlation and using non-parametric Mann-Kendall test.

   b. OPTIONAL: Append current year's value to longterm plots by year from Trends Report, without updating smoothing function.

Snowpack and Snow Water Equivalent

1. Plot daily SWE from representative SNOTEL and snowcourse stations to show timing of accumulation and ablation (for example, see Gray et al. 2010).
2. Graphic showing mean SWE for 1 April from representative SNOTEL and snowcourse stations for the past $\geq$10 years and departure of the annual 1 April means from normals or the decadal or longer mean.
3. Graphics showing monthly mean SWE from representative SNOTEL and snowcourse stations and the departure of the mean from the mean of the past $\geq$10 years noting where months are in the lowest (<20%) or highest percentiles (>80%).
4. Use SNOTEL data to describe annual timing variables: 1st snow on, last snow off, snowcover period.
5. Lake ice off dates for Jackson Lake (GRTE). Lake ice off dates for Jackson Lake have been recorded since 1933 and are available from the Bureau of Reclamation Snake River Area Office (phone 307-543-2519). Contact as of 2009 is Larry Robinson or Keith Brooks. Because the lake freezes in sections, the ice on date is usually not recorded.
6. OPTIONAL: Monthly SNODAS maps for the region that are made available on the RMCP website rather than published in the report.

Drought

Given the difficulty of accurately defining drought and the strengths and weakness of various drought indices, report these 3 indices.

1. PDSI monthly and annual values compared to baseline
2. SPI reported for 1, 3, 6, 12 and 24 months
3. US Drought Monitor maps of the region for each season

Streamflow

1. For key stations within each park or reporting unit, provide graphics or tables of derived annual hydrograph timing variables: peak and minimum flow dates, and center of mass dates relative to normals.
2. Hydrographs of mean daily flows relative to normals.
3. Annual peak flow and the departure of peak flow from normals for the past $\geq$10 years.

Correlation among Atmospheric Indices and Climate Parameters

1. OPTIONAL: Update station and circulation values in plots from Trend Report teleconnection analyses.
2. OPTIONAL: Provide table showing status of atmospheric indices for the past year with a brief description of implications for the park or reporting unit(s).

Interpreting Climate Data

The narrative should provide a succinct interpretation of the year's climate and assist with understanding the dynamics of other park resources. Highlighting the departures from normal conditions may reveal links between climate and other vital signs.

Status reports should generally not include discussion of trends, which are covered in depth by the trend reports. Percentiles and ranks can be used to interpret those months or years that are different from average. Generally, values between 20% and 80% are considered average and should be interpreted as such. Discussion and conclusions should highlight conditions that differ from average and present an integrated narrative of conditions across the domain. Network staff will consult with a climatologist while writing the report, and/or have a climatologist review early reports to improve the interpretation of climate data.

Submitting Report to WASO

Once the report is completed, the network program manager should submit it to appropriate park staff and others for review. After addressing review comments and suggestions, submit to the Natural Resource Publications Office following the directions found at:
http://www.nature.nps.gov/publications/NRPM/index.cfm

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Rocky Mountain Climate Protocol SOP Trend Analysis and Reporting

Greater Yellowstone & Rocky Mountain Networks: March 2011 version

1 - Change History

Revision History Log

Previous Version #	Revision date	Author	Changes made	Section and paragraph	Reason for change	New Version #
1.0	20101216	Ashton	Minor formatting			2010
2010	March 4, 2011	Rob Daley – GRYN, with input from others at GRYN, ROMN, SIEN	Minor changes for clarity.	Various	Scheduled Review	March 2011

2 - Background and Approach to Trend Reporting

As described in the protocol narrative, the Climate Variability and Trends Report presents analyses of inter-annual variability, long term historical trends, and teleconnections with hemispheric climate patterns (e.g., the PDO) for temperature, precipitation, snowpack, drought and streamflow. The overall objectives of this reporting process are: (1) to provide scientifically-defensible analyses of variability and trends of five climate parameters, and (2) to create high-quality climate datasets that can be used as covariate data in the analysis of other vital signs. The purpose of this report is to provide park management, researchers and park interpreters with reliable, periodic and pertinent assessments of changes in park climates. Unlike climate status reports, trend reports will include statistical comparisons to the established 30-year “climate normals” period or the period of record (Kittel et al. 2010). Other important differences between the climate status reports and the climate trends reports are: the reporting time frames (1-3 years vs. 5-10 years), the number of stations used (as many as feasible vs. a few key high-quality stations), and the level of QC (limited vs. extensive).

To describe the *variability and trends* of a climate in a scientifically-defensible manner requires a substantial investment in quality control (Kittel et al. 2010). Implementing techniques in keeping with climate-community standards is beyond the scope of what can be done with current I&M network staff. Therefore, preparation of the trend reports will require collaboration and/or contracting with a climatologist. Because climate change is a high-profile, contentious topic, in the absence of such expertise, reliance on less than high-quality data for these monitoring goals would pose a strong risk to the I&M Program’s credibility. The consensus of outside experts at the 2009 Climate Data Analysis Workshop (Kittel et al. 2010) was that, unless able to implement a protocol on par with climate community-standards, the networks should not attempt to evaluate and report on long term climate trends.

What are the criteria for successfully reporting on inter-annual variability and trends? First, the dataset creation methods must match the analysis requirements. As described in Kittel et al. (2010), dataset development must be highly integrated with the scientific questions being asked and the intended climate analyses. The specific monitoring objectives of the RCMP determine the framework of and analyses needed in the trends report. Each monitoring objective will be addressed analytically or an explanation will be provided as to why the analysis objective could not be met. Other criteria for successfully reporting on inter-annual variability and trends include that the dataset correction and analysis techniques are defensible and follow well-established, best practices of the climate science community and that the development process is transparent and well-documented (Kittel et al. 2010). Ultimately, the report should be suitable for publication in a peer-reviewed climatological journal.

This SOP provides an overview of the trends report preparation process and the anticipated scope and content of trends reports. It is designed to supplement guidance from the I&M network staff during the preparation of the trends reports by a collaborating or contracted climatologist.

3 - Trends Report Processing

In considering the overall processing of trends reports, it should be recognized that two products will result from this effort:

> (1) trends reports which will be available in print and online. These reports also provide context for the climate status reports that are completed every 1-3 years; and
>
> (2) high quality climate datasets that have undergone rigorous quality control measures that are appropriate for the intended analyses. These datasets must be thoroughly documented to track all quality control procedures.

Data development, analysis and reporting tasks include (figure 1):

- Identification of data sources and station selection per climate zone or reporting region
- Data acquisition
- Data quality control
- Data analyses
- Reporting
- Documentation, archiving and providing access to data

Preparation of the trends reports begins with identifying the key stations that represent each park or climate zone (SOP Station Selection). Reporting will be based the network domains, and on parks or climate zones within parks. Climate zones represent areas with internally consistent temporal dynamics; zones are identified through a multivariate, multi-timescale approach (SOP Defining Climate Zones). Once a few key stations per reporting unit have been identified, data should be downloaded and processed according to anticipated analyses (figure 2; Kittel et al 2010, Kittel 2009). To avoid data correction techniques interfering with analyses, it is helpful to lay out correction technique processing steps against the climate dynamical features being evaluated and the assumptions of analytical techniques being applied (Kittel et al. 2010). As previously noted in the protocol narrative, this will lead to different lineages of data being created to address different sets of questions, with different corrections applied or bypassed (Kittel et al. 2010; Kittel 2009).

In identifying specific techniques for data analysis, we refer to the I&M Technical Report *The Development and Analysis of Climate Datasets for National Park Science and Management* (Kittel 2009) and the current climatology literature (e.g., Weiss and Overpeck 2005, Pederson et al. 2009). Kittel (2009) provides overall strategies for working with climate data and a primer on techniques for handling data errors, inhomogeneities, and missing values; event, variability and trend analyses; and regional and teleconnection analyses. The specific analysis techniques used in trends reports should be subject to ongoing evaluation so that the RMCP remains current with the climate community's well-established best practices. However, any substantial change to analysis methods must be carefully considered if it will warrant reprocessing of the historical or baseline dataset. Whenever possible, data analysis will be performed using R project (R Development Core Team 2007) software and code will be made available on the RMCP Web site.

The content of trends reports should generally follow that of a scientific publication and is outlined below. This outline as well as Kittel et al. 2010 provides general guidance on the scope and content of trend reports; however the specific presentation of the reports may be different from what is suggested here. The narrative of the report should integrate information from across variables, and should highlight results at the park or climate zone scale as well as across the network domain. Trend reports will be prepared for entire networks or multiple networks, rather than on an individual park basis.

I. Executive summary
II. Introduction
III. Data acquisition, quality control, and analysis methods
IV. Results and discussion
   a. Variability/teleconnections and trends - narrative of the 5-10 year period from a spatiotemporal perspective.
   b. Daily structure/extreme value analysis - discussion of variation and change in the probability of extreme events and other features of daily frequency distribution.
   c. Interannual variability – discussion exploring temporal patterns by zone (reporting unit) and the domain, integrating across variables and noting spatial connections to:
      i. Region – regional coherence
      ii. Hemispheric circulation – teleconnections
   d. Regime shifts – discussion exploring temporal patterns by zone (reporting unit) and the domain, integrating across variables and noting spatial connections to:
      i. Region – regional coherence
      ii. Hemispheric circulation – teleconnections

e. Longterm trends – discussion exploring temporal patterns by zone (reporting unit) and the domain, integrating across variables and noting spatial connections to:
    i. Region – regional coherence
    ii. Hemispheric circulation – teleconnections

V. Integrative summary and conclusions (more specific and comprehensive then the executive summary)

VI. Literature cited

A key element of successfully reporting on interannual variablity and trends as well as providing useful datasets is making the dataset development process transparent to network and outside users. As described by Kittel et al. (2010) transparency is accomplished through:

- Thorough, up-to-date documentation for each dataset lineage that includes processing methods and their assumptions for station selection, quality control and correction, temporal and spatial aggregation. The intended uses of each dataset as well as any caveats regarding the data should be clearly stated.
- Version control – particularly given that the RMCP calls for multiple dataset lineages. Version control should be sufficient to reverse any correction, and should include archiving the original raw data.
- Open online access for the final datasets. This open access permits critical review by outside users, giving another level of quality control.

Upon completion of the trends report, all datasets and the associated metadata are transferred to the data managers to archive and make available directly or by request via the RMCP Web site. Regular communication between I&M network data managers and the climatologist(s) performing the data QC and analysis will be critical to ensure the proper transfer and handling of datasets and metadata by the I&M networks. Trend reports will be published in a peer-reviewed climatology journal and/or as a Natural Resource Technical Report. Additional analyses, graphics or text not included in the report or publications may be posted on the RMCP Web site.

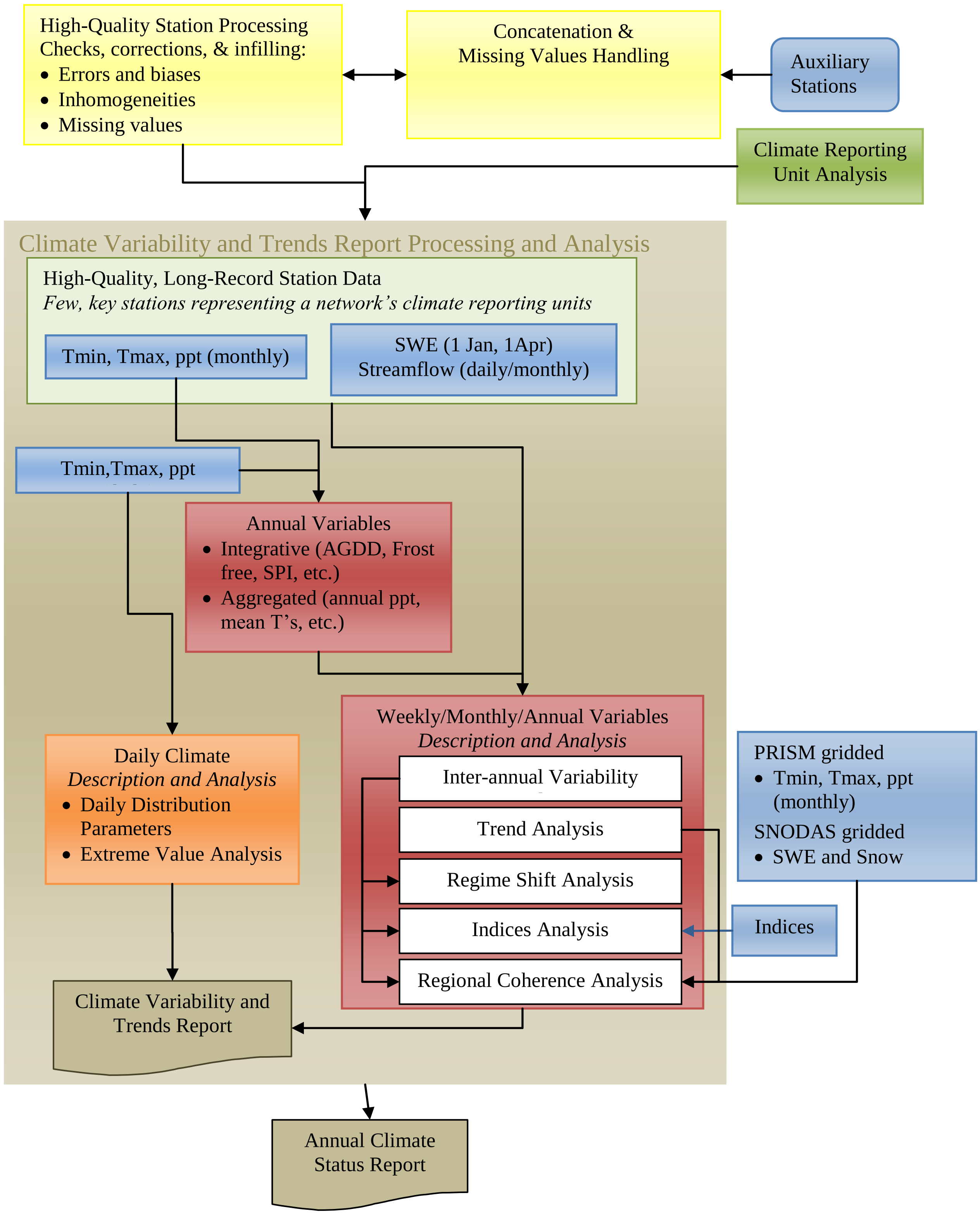

Figure 1 Overview of the processing for inter-annual variability and trends reports, taken from Kittel et al. 2010.

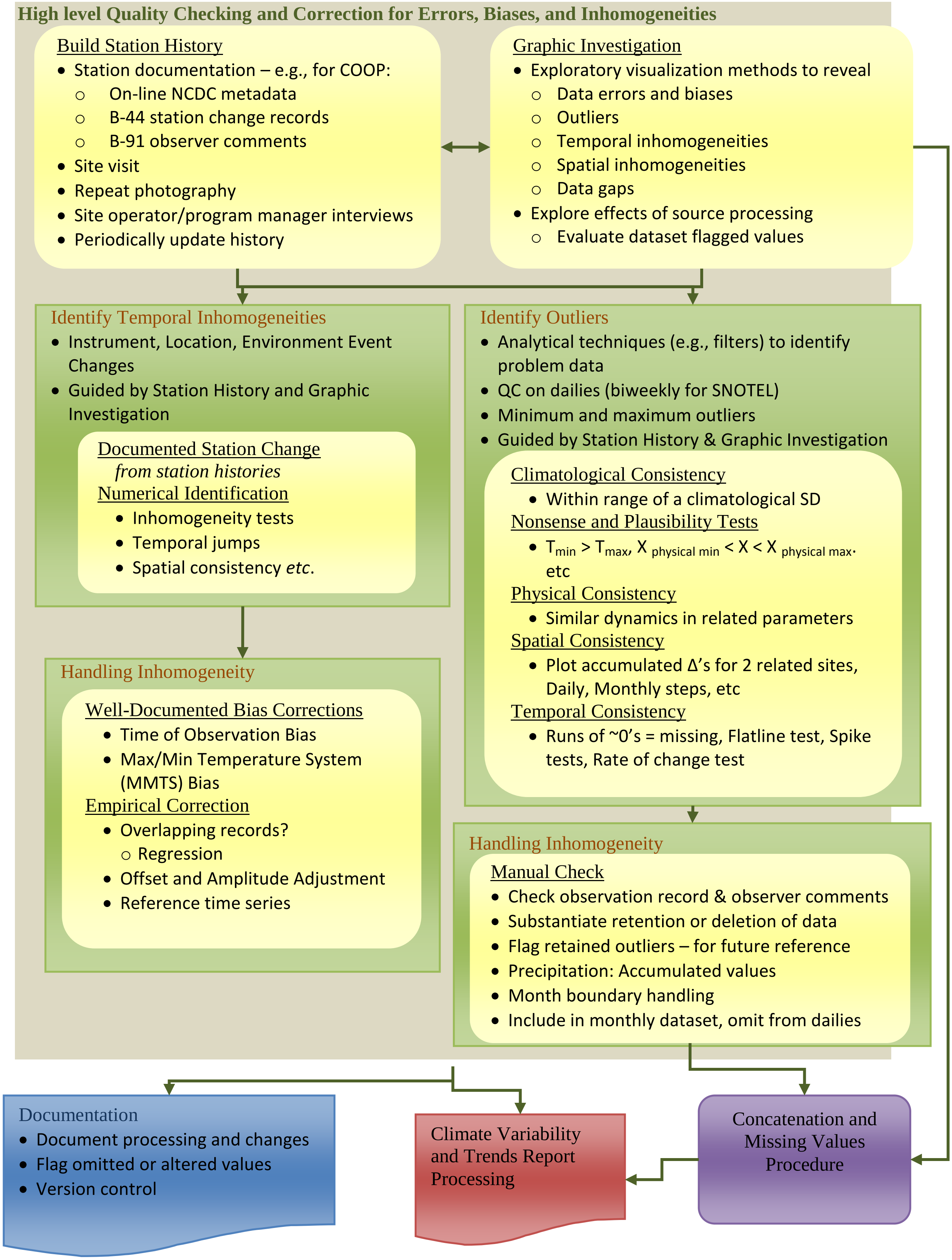
High level Quality Checking and Correction for Errors, Biases, and Inhomogeneities
Build Station History
• Station documentation – e.g., for COOP:
○ On-line NCDC metadata
○ B-44 station change records
○ B-91 observer comments
• Site visit
• Repeat photography
• Site operator/program manager interviews
• Periodically update history
Graphic Investigation
• Exploratory visualization methods to reveal
○ Data errors and biases
○ Outliers
○ Temporal inhomogeneities
○ Spatial inhomogeneities
○ Data gaps
• Explore effects of source processing
○ Evaluate dataset flagged values
Identify Temporal Inhomogeneities
• Instrument, Location, Environment Event Changes
• Guided by Station History and Graphic Investigation
Documented Station Change
from station histories
Numerical Identification
• Inhomogeneity tests
• Temporal jumps
• Spatial consistency *etc.*
Identify Outliers
• Analytical techniques (e.g., filters) to identify problem data
• QC on dailies (biweekly for SNOTEL)
• Minimum and maximum outliers
• Guided by Station History & Graphic Investigation
Climatological Consistency
• Within range of a climatological SD
Nonsense and Plausibility Tests
• $T_{min} > T_{max}$, $X_{physical\ min} < X < X_{physical\ max}$, etc
Physical Consistency
• Similar dynamics in related parameters
Spatial Consistency
• Plot accumulated Δ's for 2 related sites, Daily, Monthly steps, etc
Temporal Consistency
• Runs of ~0's = missing, Flatline test, Spike tests, Rate of change test
Handling Inhomogeneity
Well-Documented Bias Corrections
• Time of Observation Bias
• Max/Min Temperature System (MMTS) Bias
Empirical Correction
• Overlapping records?
○ Regression
• Offset and Amplitude Adjustment
• Reference time series
Handling Inhomogeneity
Manual Check
• Check observation record & observer comments
• Substantiate retention or deletion of data
• Flag retained outliers – for future reference
• Precipitation: Accumulated values
• Month boundary handling
• Include in monthly dataset, omit from dailies
Documentation
• Document processing and changes
• Flag omitted or altered values
• Version control
Climate Variability and Trends Report Processing
Concatenation and Missing Values Procedure

Figure 2 (preceding page). Overview of quality control procedures for trends reports.

4 - Literature Cited

Kittel, T. 2009. The Development and Analysis of Climate Datasets for National Park Science and Management: A Guide to Methods for Making Climate Records Useful and Tools to Explore Critical Questions. Final draft report (Dec. 10, 2009) prepared for the National Park Service Inventory and Monitoring Program. University of Colorado, Institute of Arctic and Alpine Research, Boulder, Colorado, USA. 91 p.

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Weiss and Overpeck 2005

Rocky Mountain Climate Protocol SOP Sharing Climate Data, Information, and Reports

Greater Yellowstone & Rocky Mountain Networks: March 2011 version

1 - Change History

Revision History Log

Previous Version #	Revision date	Author	Changes made	Section and paragraph	Reason for change	New Version #
1.0	20101216	Ashton	Minor formatting			2010
2010	3/4/2011	Rob Daley – GRYN, with input from others at GRYN, ROMN, SIEN	Incorporate a larger view of sharing climate data and information. Discuss various modes of data and information sharing.	Throughout	Scheduled review	March 2011

2 - Introduction

Effectively delivering relevant climate information to parks involves a collection of systems, processes, and services that will necessarily evolve to meet the information needs of park staff. Networks will publish and share printed protocols, related standard operating procedures, and scheduled reports in NRInfo. Published climate status reports and climate trend reports for network parks will list and describe data sources used, including data quality reviews and results, and how to access both original and quality-checked data sources. Additional climate related data and information may be provided online as network and park staffs identify, evaluate, obtain, and appropriately use climate-related data for understanding land and resource management issues and concerns. Some data sets may be accessed by linking directly to the online service of the original data provider (PRISM data is a possible example). Park personnel and others may require data and information beyond what is used to meet the stated objectives in the RMCP. Parks are encouraged to partner directly with networks and the NPS Natural Resource Program Center to evaluate and meet these additional requirements.

3 - Sharing Data Used for Reporting

The ‘Data and Methods’ section of each status report describes data used in report preparation (see SOP Status Reports). Data used in climate trend analysis and reporting are described in the report section dealing with data acquisition, quality control, and analysis methods (see SOP Trend Analysis and Reporting).

Create and maintain directions for accessing data used for climate reporting on network web and/or SharePoint sites following current NPS Inventory and Monitoring Division guidelines for consistently distributing information about resource monitoring topics (vital signs) (National Park Service. 2009).

Make every attempt to avoid duplicating information that is available from other trusted and stable sources. Briefly describe the procedures used to identify, obtain, quality-check, process, and use the source data for reporting, and provide a link to the complete SOP or other documentation for further details. Explain how data acquired, processed, and used for reporting may differ from other available data sources and other reporting procedures so that the reader understands the purpose and limits of data used to meet RMCP objectives.

4 - Sharing Published Material

Maintain current and previously published monitoring protocol and standard operating procedure documents in NRInfo that are included as links on each network's web and SharePoint sites. Publish scheduled status reports and trend reports in the NPS Natural Resource Report Series, upload these to NRInfo, and link to them from each network's online information system, including internal and external web and SharePoint sites.

5 - Sharing Tools for Data Acquisition, Processing, and Reporting

Many of the data automation and reporting tools developed to meet RMCP objectives are useful for working with the same or other data sources to inform other objectives outside the scope of network activities.

Provide links to Python code, R scripts, and other useful automation tools on network web and/or SharePoint sites. To prevent duplication and ensure synchrony, always identify and link to the master repository of these tools rather than providing a local copy.

Maintain and provide adequate documentation and instructions for using the available tools.

6 - Sharing Dynamic Information Online

Networks may develop online content to supplement scheduled RMCP reports and help meet park information needs with more frequent and dynamic reporting elements, and/or that centralize relevant information from multiple sources. For example, network web sites could provide static or dynamic summary and 'departure from normal' graphs for common parameters such as precipitation and max and min temperature by month. Before developing this type of online content, carefully assess whether the work to provide and maintain such provisional and/or final products is feasible for network staff to accomplish and will truly meet park information needs.

7 - Sharing Extended Data and Information Resources

Provide and maintain a list of links on network web and SharePoint sites to other online climate resources and services. Some examples are listed in table 1.

Include text on the web page to encourage users to develop a complete understanding of the relevance, applicability, and limitations of products and information from these web sites that are supplemental to the RMCP climate status and trends reports.

Table 1. Supplemental Climate and weather resources for Rocky Mountain Region NPS units.

General Topic	Website
Current weather, forecasts, and summaries of historic climate data	http://www.nws.noaa.gov/
	http://weather.unisys.com/
	http://www.wrcc.dri.edu/NEWWEB.html
	http://www.ncdc.noaa.gov/oa/ncdc.html
	http://www.weatherbase.com/
State climate resources	http://ccc.atmos.colostate.edu/
	http://climate.ntsg.umt.edu/
	http://www.wrds.uwyo.edu/sco/climate_office.html
Drought information for the US, the West, and by state	http://drought.unl.edu/DM/DM_west.htm
	http://www.drought.gov/portal/server.pt/community/drought.gov/202/area_drought_information?mode=2&region=west&x=13&y=11
	http://lwf.ncdc.noaa.gov/oa/climate/research/drought/drought.html http://www.drought.unl.edu/monitor/monitor.htm
	http://co.water.usgs.gov/drought/index.html
	http://mt.water.usgs.gov/drought/
	http://wy.water.usgs.gov/projects/drought/index.html
Snow information including maps of accumulation and SWE	http://www.nohrsc.noaa.gov/nsa/
	http://www.nohrsc.noaa.gov/nsa/index.html?year=2009&month=6&day=3&units=e&region=Central_Rockies
	http://www.nohrsc.noaa.gov/nsa/index.html?year=2009&month=6&day=3&units=e&region=Northern_Rockies
Streamflow information from the USGS	http://wdr.water.usgs.gov/
	http://water.usgs.gov/waterwatch/?m=real&r=co&w=real%2Cmap
	http://water.usgs.gov/waterwatch/?m=real&r=mt&w=real,map
	http://water.usgs.gov/waterwatch/?m=real&w=gmap&regions=wy
NPS resources	http://www.wrcc.dri.edu/nps/reports.php
	http://www.nps.gov/romo/planyourvisit/weather.htm
	http://www.nps.gov/glac/planyourvisit/weather.htm
	http://www.nps.gov/libi/planyourvisit/weather.htm
	http://www.nps.gov/grko/
	http://www.nps.gov/flfo/planyourvisit/weather.htm
	http://www.nps.gov/grsa/planyourvisit/weather.htm
	http://joomla.wildlife.org/ccbib/
Climate library for references on climate change and wildlife	http://nccw.usgs.gov/
National Climate Change and Wildlife Center	http://www.nrmsc.usgs.gov/MTclimate/
Climate Analysis Tools (example R code)	

8 - Creating and Maintaining Shared Information

Follow the schedule in Table 2 to develop and maintain the required online resources and content.

Table 2. Example list of RMCP online content, assignments and schedules.

Content Element	Responsible Party	Schedule
Overall site design and development	I&M Network data managers with input from the RMCP development team	Initial and ongoing
Coordinating site content with other online resources	I&M Network ecologists & data managers working with providers of content on other web sites	Initial and ongoing
List of climate and weather resources	I&M Network ecologists	Prepare initial list and update annually or more frequently if necessary
Reporting schedule	I&M Network ecologists	Initial and ongoing
Climate status reports	I&M Network ecologists	Provide status reports for posting as soon as they are published/available. Continuously ensure that all current and past status reports are available online.
Climate trends reports	I&M Network ecologists	Provide trends reports for posting as soon as they are published/available. Continuously ensure that all current and past trends reports are available online.
Climate monitoring protocol	Project leader(s) from each participating office	Continuously ensure that all current and past Rocky Mountain Climate Monitoring protocols are available online.
Climate monitoring procedures (SOPs)	I&M Network ecologists & data managers	Continuously ensure that all current and past standard operating procedures for the Rocky Mountain Climate Monitoring protocol are available online.
Climate monitoring tools for automating computer processing	I&M Network ecologists & data managers	Continuously ensure that all current and past data acquisition, processing, analysis, and reporting tools for the Rocky Mountain Climate Monitoring protocol are available online.
Static data sets used in climate status reports	I&M Network data managers	Ensure that fully qualified and documented data sets used in climate status reporting are accessible directly online or by request to a project contact. Input and derivative data sets meeting these criteria will be made available concurrently with the release of each climate status report.
Static data sets used in climate trends reports	I&M Network data managers	Ensure that fully qualified and documented data sets used in climate trends reporting are accessible directly online or by request to a project contact. Input and derivative data sets meeting these criteria will be made available concurrently with the release of each climate trends report.
Data documentation	I&M Network data managers	Prior to all initial and subsequent release of data sets.

9 - Literature Cited

National Park Service. 2009. I&M Network Data Management Web Authoring http://www1.nrintra.nps.gov/im/datamgmt/webdev/index.cfm. Accessed 3/8/2011.